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EDITORIAL NOTES.

AT this season of the year the conduct of the GEOLOGICAL MAGAZINE is beset with peculiar difficulties. Owing to the holidays our contributors are scattered far and wide, letters have to be re-addressed often more than once, and the return of proofs is unavoidably delayed. Owing to distance from libraries, also, it is often impossible for either author or editor to verify references, or to keep in touch with the latest developments of any subject. Furthermore, the supply of reviews tends to fall off. Another great drawback to the holiday season is the impossibility of collecting information of recent events of personal interest in the geological world. The Editors take this opportunity of saying that they are always grateful for news of new appointments to geological posts at home and abroad, and other similar matters of interest to the geological world. Our readers will be able to judge for themselves as to the kind of thing that is wanted. Any help in the communication of such items will be gratefully received. It may perhaps be permissible to mention here one other matter of a quasi-editorial nature. Those of our contributors who desire separate copies of their papers or other communications should make a point of sending their orders for the same to the Editor along with their corrected proof. From motives of business economy it is necessary to break up the type almost immediately after the issue is printed off, and unless orders are received before we go to press separate copies cannot be guaranteed.

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MESSRS. W. HEFFER & SON, LTD., Cambridge, have in the press a book entitled *Notes on Geological Map-Reading*, with forty illustrations, by Alfred Harker, LL.D., F.R.S., F.G.S., Fellow of St. John's College, and Reader in Petrology in the University of Cambridge. Probable price, 3*s*. 6*d*. net. The object of these notes is to teach the student to visualize a geological map as in three dimensions, and to show him that the questions which present themselves to the field-geologist reduce to exercises in very elementary geometry. This simplicity is gained by reckoning all slopes and dips as gradients, which enables one to dispense alike with trigonometry and with the protractor. The amount of dip, the thickness of a formation, the throw of a fault, etc., are thus measured directly upon a contoured geological map by the use of the scale alone.

ORIGINAL ARTICLES.

Preliminary Notes on the Geology of the Ningi Hills Northern Nigeria.

By Gerard W. Williams, D.S.O., M.C., M.I.M.M., F.G.S.

WITH PETROGRAPHICAL APPENDIX BY R. H. RASTALL, M.A., M.I.M.M., F.G.S.

THE country described in the following notes comprises the area lying between latitudes 10° N. and 11° 30′ N. and longitudes 8° 45′ E. and 10° E., and is situated in the northern portion of Bauchi province and the south-eastern portion of Kano province, Northern Nigeria.

The Delimi River runs diagonally through the area. This river, one of the chief feeders of Lake Chad, rises on the main hydrographic centre of Northern Nigeria. The three largest rivers that rise in the Protectorate—the Delimi, Gongola, and Kaduna—have their head-waters in a swampy, moorland plain that attains its highest elevation of approximately 5,000 feet at a point midway between Jos and Bukuru, near to the Rayfield Mines main camp. The Delimi River flows through Jos and Narraguta, and then plunges down the Narraguta Gorge below the native market. Thence north-easterly through Rafin Jaki camp, Deriko, and Bongwelli to Lemmi. Below Lemmi the river widens to 400 yards, and at Guaram it is fully 1,000 yards wide. Thence the river flows past Kategum to join the Hedaji River, and the united stream, then known as the Yo River, winds deviously eastward to Lake Chad. The head-waters above Narraguta drain the high land of the Bauchi Plateau, and as both the main stream and its upland tributaries drain from the stanniferous granite of the 'Ngell Massif the river washes are all tin-bearing. The boundaries of this massif, on its northern side, are practically continuous with the boundary of the Plateau from Rukuba to Toro. Below the plateau the Delimi has been proved tin-bearing for nearly 50 miles—as far as Lemmi. The bulk of this tin is not derived from the stanniferous granites of the plateau, but is fed to the main stream by tributaries draining the rugged group of ranges known as the Jengre Hills, of which the Buji Peak forms the highest point. The Narraguta Gorge is excavated through a series of gniesses and other ancient crystalline rocks, and the bed-rock of the river as far as Lemmi is almost exclusively composed of gneisses. Below Biberi the valley widens out into a broad flood plain, which attains a width of from 10 to 12 miles at Bongwelli. From the floor of this valley rise numerous ridges and domes of granite, which decrease in number as the river flows north-east from Lemmi. From Lemmi to Lake Chad (with the exception of a few isolated granitic hummocks) the flood plain widens out on to the

far-stretching plains of wind-borne sands and superficial accumulations that cover the bulk of eastern Kano and Bornu Provinces.

The traverse on which these notes were made was primarily undertaken as a prospecting tour. In consequence special attention was paid to the hilly country, as the plains, owing to their uniform covering of recent deposits, offer no exposures of the underlying rocks. Starting from the main camp of the Bongwelli Mines the route ran north through Chow and Sabon-Garri to the main camp of the Yarde Kerri Group Mines. Thence easterly to the Minna camp on the river of that name, and thence along the southern face of the Ningi Hills. Skirting the western hills of the Ningi massif the route ran over broad plains in a north-easterly direction to the massif of the Kila Hills, which rise like a smooth-walled island from the level plain. South-east of Kila the Fagam Hills were visited, but only a portion of their granite was examined. The return journey was made along the northern face of the Ningi Hills, and thence back to Sabon-Garri. From this village the return route was westerly to Rahama and back to Bukuru by rail.

From Bongwelli to Chow the basal rocks are gneissose, but exposures are few in number. The village of Chow lies at the foot of a group of granite hills, which form a singularly perfect example of platy desquamation. The domes rise sheer from the light soil, the sides at the base being usually slightly concave and the domes are perfectly rounded. The native name for this group of hills means "breasts of a young woman", and, as is often the case in native names, the phrase is singularly appropriate.

The Sabon-Garri Granite.

This granite (100)[1] is coarse-textured with felspars (perthite) up to an inch in length. The dominant ferromagnesian mineral is riebeckite. It extends over a very wide area. For convenience I have called it the Sabon-Garri granite, for it attains its largest development between that village and the Ningi Hills.

When Chow is left behind the country changes rapidly in appearance, and west and north extends a wide area of rugged granite ridges and domes. On the slopes of the valleys the thin surface soil contains large numbers of felspar crystals derived from the weathered granites.

Three miles north of Chow a very large dyke of ægirine-riebeckite-porphyry (101) forms a low ridge striking east–west, and numerous smaller dykes of similar material are visible in the granites and maintain the same general strike. Slight marginal chilling of the dyke is usually noticeable. A few miles further north a series of small dykes of devitrified rhyolite (102) are exposed in the valleys lying between the granitic domes near to Taura village.

At Tema, 5 miles south of Sabon-Garri, the typical granites are

[1] The numbers in brackets refer to specimens now deposited in the Sedgwick Museum, Cambridge, and described in the appendix to this paper.

exposed in large, slightly convex bosses. In the bed of the Sabon-Garri River is an exposure of a coarse-textured granulitized microcline granite of highly acid characteristics (103), and immediately north is a small well-weathered exposure of highly foliated muscovite granite. The village of Sabon-Garri lies at the foot of three domes of granite (105).

From the village to Duchin Chanya Cherigi (lit. the hill that resembles a pigeon's breast—another example of apt nomenclature), the track runs in a general northerly direction, passing between numerous ridges and domes of Sabon-Garri granite. Aplitic intrusions are not uncommon. Approaching Chanya Cherigi foliation increases and in many places the granites are strongly gneissose (106).

The dark mass of Chanya Cherigi, 3,369 feet, which rises 1,000 feet above the plain level, forms a conspicuous landmark. This hill is the highest of a series of granite hills, oval in ground plan, the longer axis running due north and south. The granites in the neighbourhood show marked effects of dynamo-metamorphism. The general foliation is north and south, and the main crush zone, which extends through Gora Hill and Chanya Cherigi, is well mineralized. A well-defined lode forms the crest of these two hills, and is traceable for some $2\frac{1}{2}$ to 3 miles south and north. Tin and wolfram occur in narrow, parallel, quartz-filled veins. The country rock is an altered granite containing topaz. (C.C. 4–7.) Numerous lenticular masses of aplite occur in the immediate neighbourhood. (C.C. 2–3.)

Many exceedingly rich "floaters" of tin ore (some assaying up to 50 per cent, SnO_2) occur on the slopes of the hills and in the valley below. Some of these "floaters" are exactly similar in appearance to the rich ore from the "Bushveld" tin mines (South Africa). In places the granite on the slopes of the valleys tends to weather into flat sheets, but the usual weathering is into rough blocks; many of the isolated boulders display a tendency to "mushroom" shape, due to the erosion by blown sand.

In the vicinity of Yarde Gongome, the main camp of the Yarde Kerri mines, the prevailing rocks are gneisses, and these extend northwards to Burra, at the western end of the Ningi Hills. North-east and east from Yarde Gongome the Sabon-Garri granites come in, and form a group of characteristic domes in the neighbourhood of Minna camp and near to Dogon Daji on the Minna stream.

The boundary between the Sabon-Garri granites and the gneisses is ill-defined. Contact metamorphism is entirely lacking, and masses of gneiss are frequently included in the granites. In the neighbourhood of Keffi Filani veins of pegmatite cross and recross the boundary, and the whole contact is foliated in a general equatorial direction. This foliation, which affects both granites and gneisses, was probably induced by the intrusion of the Ningi granites, the longer axis of which runs due east and west.

The dominant foliation in the country between Chow and Chanya Cherigi is distinctly meridional. Between Dogon Daji and Keffi

Filani a broad outcrop of a remarkably fresh gabbro dyke (107) exposed for a width of some 40 to 50 yards, forms a low ridge striking east and west. This was the only basic intrusion encountered during the traverse. At Keffi Filani there is a small outcrop of a somewhat granulitized, gneissose granite (108, 110), which is different in character both to the Sabon-Garri and the Ningi granites. Only two exposures were observed, one forming a few isolated knobs and the other forming a low ridge running east and west. This granite appears to be intermediate in age between the typical granites. It appears to be intrusive in the Sabon-Garri granite, but has been crushed as a result of the movements that accompanied the intrusion of the Ningi massif. No contact with the Ningi granite was observed.

The Ningi Granites.

North of Keffi Filani the Ningi granites are first seen in the valley of a small stream that heads near Ka and flows south through Keffi. The well-marked contact, with chilled edges, is at this point against the old granites and gneisses. Travelling eastward towards Ningi the track skirts a low range of gneissose hills (109), with bars of harder, more siliceous rock (111), behind which rise the higher hills of the Ningi granite.

Ningi itself, lying securely behind triple walls at the head of a small valley, was formerly the chief village and fort of a Pagan tribe who conducted an extensive and profitable trade in slave raiding. The "new" granites come in about 1½ miles north of the village. The contact is clearly marked (113, 114). At the point traversed the Sabon-Garri granite forms large, flat, bare sheets (112) or slightly convex turtle backs, and the newer granite rises steeply and displays a certain horizontal jointing that resembles dry walling on a cyclopean scale. The Ningi granite (115) is a riebeckite granite, and is similar to the granite forming the Kila and Fagam massifs.

A large dyke, or series of parallel dykes of a dark-green rhyolite, starts at Ningi and runs north-easterly through the villages of Ari and Teffi. At Teffi the dyke channel is occupied by porphyries as well as rhyolites (117, 118), whilst porphyries (138) and ægirine-rhyolites (139) are exposed between Wurji and Guaram.

Between Ari and Teffi these dyke-rocks have resisted denudation more than the surrounding granites and gneisses, and stand out boldly, forming the southern wall of the hills. Passing north-east towards Wurji they form numerous isolated grassy hills and low ranges. A quartz-riebeckite syenite occurs at Teffi, lying apparently in contact with the Ningi granites and the porphyries (119, 120). At the crossing of the Delimi between Teffi and Wurji orthophyre (121) and porphyry (122) are exposed in the river bed, and exposures occur in the hills north of Wurji (123).

The syenites reappear at Guaram, where they form several low hills lying near to the town (129). The contact rocks in the north-

easterly portion of the Ningi massif are syenites and porphyries, the latter predominating: small andesitic veins are found in the porphyries and in the gneisses, but never in the syenites or Ningi granites. North of the porphyries low outcrops of old granite are sometimes visible (140). Passing westward along the northern edge of the Ningi massif porphyries and rhyolites form the contact rocks as far as Lumbo, but thereafter these intrusives thin out and the contact with the old crystalline rock is obscured by superficial drifts. Near Burra contact with gneiss is well defined. The Ningi massif measures about 30 miles east and west, and averages 6 miles in width. The hills are rounded, and the highest points attain an elevation of 2,850 feet. The granite is essentially a riebeckite-biotite type, much more fine in grain than the ancient Sabon-Garri type but similar in general composition.

The Kila Granites.

The Kila Hills rise abruptly from a level plain. The central peak is probably about 3,300 feet in height. Although no contact rocks are visible chilled margins (126) are to be seen towards the northern edge of the hills. The granite is essentially a riebeckite granite (124, 125). At Jugwa, near the centre of the massif, the riebeckite forms large crystals up to 2½ inches in length. The surface soil, which is deeply banked in the valleys, is obviously mostly of æolian origin. North and north-east of the hills stretch the great plains of Kategum, whose level surface of fertile wind-borne soil is unbroken by hill or ridge.

The Fagam Granites.

Travelling south-east from Kila to Guaram the route follows the main Kano–Nafada–Lake Chad road. There is only one exposure of gneiss and the soil is very deep. In a well at Yelua the water-level was 37 feet. The soil was composed of alternate layers of fine sands and marly clays, the latter probably of lacustrine origin. Near Guaram rest-house are a few low ridges of syenite (129), and south of the town numerous "floaters" of rhyolite and porphyry occur.

Like the Kila Hills the Fagam granites rise abruptly from the plains, and the deep soil is banked up the level-floored valleys and against the northern sides of the massif.

A few exposures occur about a mile from the hills: a biotite-granulite (130) forms a cluster of boulders and near by the track climbs steeply over an outcrop of quartz-syenite-porphyry (131).

The massif itself is of considerable extent, and from a hill 2,500 feet in height, which lies about 1½ miles from the stockaded village of Fagam, the granite can be seen stretching well away to the westward of Gadama. The massif is composed of a somewhat coarse-grained riebeckite granite (133). In places the riebeckite tends to form bands (134). Pegmatite veins containing large riebeckite crystals up to 2 inches in length were noted (135). Chilled margins and

aplitic veins (137) were observed to the south-west of Fagam, but the actual contacts were covered with superficial accumulations.

The Intrusive Rocks of the Area.

With the exception of the gabbro dyke near Keffi Filani all the intrusives are acid in character. The gabbro, which is exceedingly fresh, is probably referable to the mid-Tertiary period of volcanic activity, of which one important focus existed near Burrin, some 140 miles to the north-west of Ningi. The characteristic intrusions in the Sabon-Garri granites are rhyolites and ægerine-riebeckite-porphyries. Rhyolites, soda-rhyolites, and porphyries form a broad belt extending from Ningi to midway between Wurji and Guaram, and, judging by "floaters", the belt passes in an easterly direction near to the village of Duchi, a few miles south of Guaram.

Syenites occur in close proximity to the rhyolites at Teffi and at Guaram. In some cases the rhyolites are intruded into the porphyries. Dykes of quartz-felspar rock, very hard and resisting weathering well, are frequently encountered in both the gneisses and the Sabon-Garri granites. No. 111 is typical of this rock, which often forms "bars" across the hill rivers.

Rock Succession in the Area.

The following table indicates the general succession as observed during the traverse:—

Pliocene and Post-Pliocene .	Æolian sands.
	Lacustrine sands and clays.
Tertiary (?)	Gabbro dyke.
Mesozoic	Ningi–Kila–Fagam granites (Ningi type).
	Ningi–Wurji rhyolites.
	,, porphyries.
	Ningi–Guaram syenites.
?	Keffi Filani granite.
Archæan	Ægirine–Riebeckite porphyries.
	Banded rhyolites.
	Riebeckite Granites—Sabon-Garri type.
	Gneisses and other crystalline rocks forming basal series of Northern Nigeria.

Surface Accumulations and Drainage.

North and north-east of Ningi the soil is markedly æolian in origin. During the traverse a number of test pits were sunk in the valleys of the Kela and Fagam Hills and in the drifts along the edge of these massifs. These pits almost invariably disclosed a sequence of light sands, largely wind-blown in origin, and grey or whitish clays, flocculent in water, and containing fine, wind-blown sand.[1] The clays appear to be lacustrine in origin. Near Fagam a pit sunk at the edge of the granite yielded a layer of marly clay at 12 feet (water level), which contained decomposed fragments of a shell of

[1] Cf. *The Geography and Geology of Northern Nigeria*, pp. 215 et seq.

Limnæa (sp. ?). In the alternating sandy layers fragments of *Bulimus* (sp. ?) are sometimes found.

The valleys opening out of the hills, especially those facing north or north-east, are usually deeply filled with light, sandy soil, partly detrital and partly æolian in origin, which forms a level floor to the valley. A remarkable feature is the uniform absence of water-courses in these valleys. The rainfall, averaging 35 to 40 inches, falls mostly in a few torrential downpours during August and September. The rains pour down the bare granite catchments into the valleys, but sink through the soil and do not form water-courses. The whole country becomes waterlogged, and the few river beds that traverse the plains (mere grass-grown depressions) indicate the general direction in which the surface waters move towards the main course of the Delimi and Hedaji rivers. In the floods the Delimi overflows its low banks and spreads, many miles wide, across the planes. The country is very similar to the Cooper's Creek country of Australia, where one may perish of thirst one day and the next, 10 mile wide rivers pouring down from the Diamantina and Georgina country bear the Queensland flood waters to the lakes of South Australia. Water level in the dry season varies considerably. In the neighbourhood of the hills it varies from 6 to 12 feet, but in the plains increases to 40 feet. Further north-east the depth increases to 120 feet in Bornu province.

Parallel to the Delimi River are a series of long, narrow, deep lagoons, often surrounded by permanent swamps. Near to Guaram is a lagoon $1\frac{1}{2}$ miles long, 250 yards wide, and 15 to 20 feet in depth.

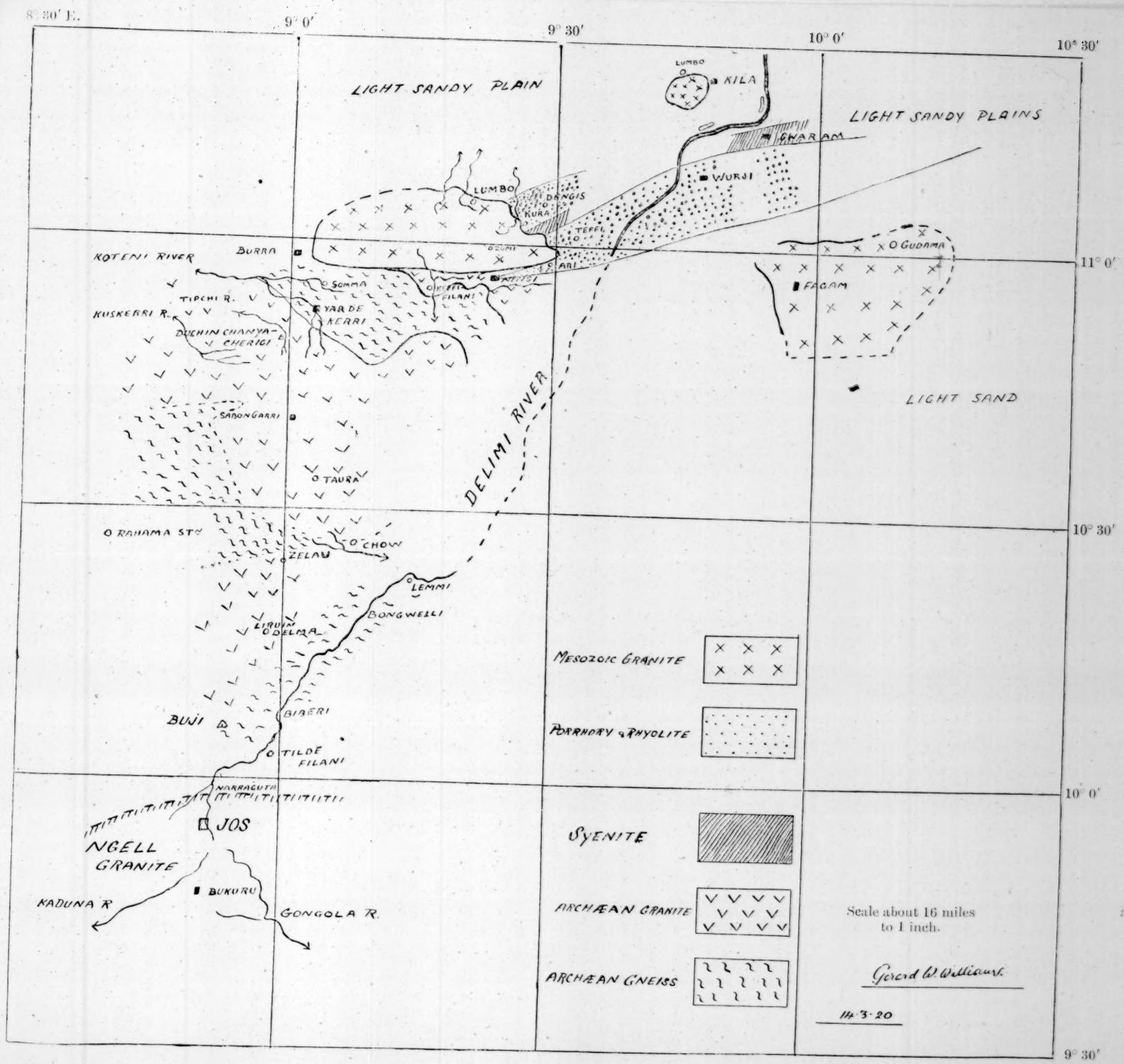
Laterites.

The horizontally bedded layers of vesicular ironstone that are so characteristic a feature of the topography of the Bauchi Plateau and which are found throughout the country between Delimi and the Ningi Hills are not developed in the light soils east of the Kila and Fagam Hills. In the immediate vicinity of the Kila granites certain bands of sand carry concretions of ironstone, but uniform lateritic sheets are lacking.

The Occurrence of Tin in the Area.

The younger granites of the Bauchi plateau, which are similar to and probably contemporaneous with the granites of the Ningi type, are well known for the tin contained in the streams draining from them. This reconnaissance, however, definitely establishes the fact that the Archæan granites of the Sabon-Garri type are also stanniferous. From Chow to Yarde Gongome all streams that drain these granites carry more or less tin in the wash, and relatively large quantities are found in the surface soils in the vicinity of lodes such as those in the neighbourhood of Yarde Kerri.

Near to Bongwelli a pegmatite stockwerk in Sabon-Garri granite sheds a large quantity of tin into the Dada Howa creek (a Delimi


8° 30' E.
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LIGHT SANDY PLAINS
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KILA
GWARAM
WURJI
DANGIS
KURA
TEFFI
LUMBO
KOTENI RIVER
BURRA
OZUMI
ARI
GUDAMA
FAGAM
SOMMA
FILANI
TIPCHI R.
KUSKERRI R.
YARDE KERRI
DUCHIN CHANYA-CHERIGI
SABONGARRI
TAURA
DELIMI RIVER
LIGHT SAND
RAHAMA STN
ZELAU
CHOW
LEMMI
BONGWELLI
LIRUN
DELMA
BIBERI
BUJI
TILDE FILANI
NARRAGUTA
JOS
NGELL GRANITE
KADUNA R
BUKURU
GONGOLA R.
MESOZOIC GRANITE
PORPHYRY & RHYOLITE
SYENITE
ARCHÆAN GRANITE
ARCHÆAN GNEISS
Scale about 16 miles to 1 inch.
Gerard W. Williams.
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tributary). Near to Zelau the streams are markedly stanniferous, especially those draining south and south-east to the Delimi valley. From the Jengre Hills several Delimi tributaries, especially the Buji and Zora, carry very considerable amounts of tin in the wash.

The Ningi granites yield tin, and several streams in the western end of these hills are being worked on a very small scale. Small quantities of tin, never in payable amounts, were found both in the Kila and the Pagam Hills. In these areas, however, the absence of defined watercourses militates against the economic concentration of the shed tin. No tin was ever found in streams draining only from the gneisses. For example, in the rivers of the Yarde Kerri Group Mines, the Gongome, Kogo, Kuskerri, and Tipchi River and river-flats which drain the Sabon-Garri type of granite produce tin in economic quanity, but the adjacent left fork of the Koteni, which drains a gneissose area, is absolutely barren of tin. This was also observed in the streams draining a large gneissose area between Begindi and Rahama.

If a generalization may be permitted at this stage I would say that tin is only found in granites that contain riebeckite—and this view derives further support from a consideration of the Mesozoic, tin-bearing granites of the Ropp–Monguna–Exlands areas in the southern portion of the Bauchi Plateau. On the other hand, it occurs equally in riebeckite granite of both Mesozoic and Archæan age; indeed, as far as the area traversed is concerned, it is far more abundant in the Archæan granites than in those of the Ningi type.

PETROGRAPHICAL APPENDIX.

The following notes are brief petrographical descriptions of the rock-specimens collected by Major Williams during the traverse described in the preceding paper. Most of the specimens have been sliced, but in a few instances weathering had advanced too far for this. These notes have purposely been made very short as it is hoped to obtain further specimens of the more interesting types and to publish a full account of the petrography of this area on a subsequent occasion. The nomenclature here adopted must be considered as provisional, since further information is needed as to the field-relations of some of the types collected, and no attempt has been made to institute comparisons with similar rocks elsewhere.

Description of Specimens.

100. *Riebeckite-biotite-granite.*—This is a rock of very coarse texture, with crystals of felspar up to an inch in length, quartz, and large patches of dark-coloured minerals. The largest felspars are perthite, the rest mainly albite, with a little orthoclase and microcline. Quartz is fairly abundant, both as large crystals and as rounded blebs in the felspar, with a little micropegmatite. The ferromagnesian minerals are riebeckite and deep brown biotite in

approximately equal amount. The accessories are abundant apatite, some fairly large zircons, magnetite, and allanite.

101. *Ægirine-riebeckite-porphyry.*—A porphyritic rock with phenocrysts of white felspar in a bluish-grey groundmass. The felspars are rather lath-shaped and up to 8 mm. in length. They consist of orthoclase and occasionally enclose a little quartz. The groundmass is a rather fine mosaic of orthoclase felspar, ægirine, and riebeckite, with a little quartz.

102. *Rhyolite.*—This rock possesses conspicuous flow-structures, shown by wavy bands of dark red and dark blue colours. It is much stained by iron oxide and other decomposition products, but under the microscope shows well-marked micropoecilitic structure, with a tendency to aggregation in spherulites. It is probably a devitrified glassy lava of acid composition.

103. *Microcline-granite.*—A coarse-textured granitic rock, considerably crushed and granulitized. It consists almost entirely of quartz and microcline felspar, with a very small quantity of muscovite. There is a slight tendency to micrographic structure. The rock is evidently of very acid composition, but it is a good deal decomposed, with much infiltration of secondary products along cracks and the boundaries of the minerals.

105. *Riebeckite-biotite-granite.*—A granitic rock of coarse texture, composed of quartz, microcline, subordinate plagioclase considerably decomposed, and riebeckite, with a little biotite. The accessories are iron oxide, apatite, and zircon.

106. *Granite.*—This specimen consists of quartz, decomposed orthoclase with some plagioclase near oligoclase, and patches of a green chloritic mineral, which may represent biotite. The rock has been much crushed, as is shown by the bending of cleavages and the twin-lamellæ of the plagioclase.

107. *Gabbro.*—A remarkably fresh rock, consisting of plagioclase felspar, diallage, hornblende, and a little biotite. The felspar has a refractive index higher than that of Canada balsam, and shows extinction angles up to 30 degrees. It is therefore of a basic character near labradorite. The diallage is very pale brown, with the characteristic purplish inclusions. There is also some colourless augite. The brown hornblende is often seen as a sort of graphic intergrowth with the pyroxene, all the enclosed patches commonly showing the same orientation. There is a little bright chestnut-brown biotite (lepidomelane). The only accessory mineral is a very little magnetite and no nepheline or analcime could be detected. The extraordinary freshness of this rock suggests that it is of much later date than any of the other specimens.

108 and 110. *Biotite-granite.*—Both these specimens, which are almost identical, are granulitized gneissose granites, composed of quartz, often in rounded blebs in the felspar, large microclines, and a little plagioclase. There are here and there small patches of micropegmatite. The coloured constituent is olive-brown biotite,

with accessory apatite and allanite, and a trace of purple fluorite. Although not apparently gneissose to the naked eye, the microscope shows that these rocks have been to some extent crushed and granulitized, though not so much so as the thoroughly gneissose types.

109. *Granite or gneiss.*—This appears to have been originally a gneissose granite with micropegmatite and without ferromagnesian minerals, but it is now so much decomposed that the original character of the felspar is indeterminable.

111. *Sheared gneiss.*—This rock consists of quartz and orthoclase without any original coloured minerals, but there is a little secondary epidote. It is very much sheared and granulitized.

112. *Biotite-granite.*—A rock of coarse texture and somewhat granulitized, consisting of quartz, microcline-microperthite, and brown biotite. It presents no features of particular interest.

113. *Porphyritic biotite-granite.*—The felspar of this rock is so much decomposed that its original character is uncertain, but it was probably perthite. The other minerals are quartz and brown biotite, and the structure of the groundmass is microgranitic.

114. *Biotite-granite.*—This specimen seems to show the contact between the granulitized gneissose granites of the ancient complex characterized by olive-brown biotite and the riebeckite-biotite granites of the later Ningi series. The two are, however, so inextricably intermingled along the margin that no clear description can be given. In this slice only a small trace of riebeckite can be identified, and the greater part of the specimen seems to consist of the older rock, more or less shattered by the later intrusion.

115. *Biotite-riebeckite-granite.*—A very much decomposed rock, composed of quartz and perthitic felspar in graphic intergrowth, with chestnut-brown biotite and riebeckite, and much iron oxide. There is no sign of crushing, and this rock evidently belongs to the younger series.

117. *Quartz-porphyry.*—A typical example of an acid hypabyssal rock with phenocrysts of quartz and twinned orthoclase; some phenocrysts consist of micropegmatite, and the quartzites show very good dihexagonal forms. The finely microcrystalline groundmass consists of quartz, felspar, and brown iron oxide. The quartz and felspar show micropoecilitic relations, and flow-banding is well marked. No ferromagnesian minerals remain, but some patches of yellow iron oxide may represent phenocrysts of biotite.

120. *Quartz-syenite.*—Very abundant orthoclase in large crystals with some plagioclase (albite and oligoclase), and a small amount of interstitial quartz. The ferromagnesian minerals are rather decomposed; mainly hornblende, but a little biotite was probably originally present. The hornblende is of a blue-green soda-bearing variety near to riebeckite, with strong pleochroism (greenish-blue, olive-brown, yellowish). There is a fair amount of accessory apatite and a little magnetite.

121. *Orthophyre.*—A porphyritic rock with phenocrysts of pink

felspar in a fine groundmass. It consists entirely of orthoclase and iron oxide, the latter representing some ferromagnesian mineral. The felspars of both generations are prismatic in form, and the structure of the groundmass is typically orthophyric. This is the dyke-facies of a syenitic rock.

122 and 123. *Porphyry.*—A conspicuously porphyritic rock, with phenocrysts of orthoclase in a fine groundmass of quartz, orthoclase, and red iron oxide. The orthoclase is much decomposed, and the original character of the ferromagnesian minerals is undeterminable. The groundmass is microgranitic in structure.

124. *Ægirine-riebeckite-granite.*—A remarkably fresh rock, consisting essentially of quartz, perthite, ægirine, and riebeckite. The felspar is entirely microperthite of a finely intergrown type, in idiomorphic crystals of tabular form. The quartz is interstitial and the last mineral to crystallize. Ferromagnesian minerals are not abundant; chiefly emerald-green ægirine in idiomorphic prisms with the characteristic slight pleochroism and small extinction angle; there are also a very few crystals of pale-brown or colourless augite. Deep blue riebeckite is much less abundant than ægirine; the larger crystals are nearly opaque even in a very thin slice. The only accessory seen is a little magnetite.

125. *Riebeckite-ægirine-granite.*—This rock is closely related to the last, the chief difference being the predominance of riebeckite over ægirine, and a slight tendency to micrographic structure. All the minerals show precisely similar characters and further description is unnecessary.

129. *Biotite-augite-syenite.*—A rock of fairly coarse texture and even grain, consisting of felspar, biotite, augite, and riebeckite. The felspar is chiefly perthite with a subordinate amount of plagioclase, having a refractive index lower than Canada balsam (albite). The biotite, which is very fresh, is of a deep chestnut brown colour, with very strong pleochroism; the augite is pale-green with slight pleochroism and very strong birefringence; therefore, probably ferriferous. There is a little deep blue-green riebeckite in ragged prisms, often intergrown with augite. The structure is hypidiomorphic, with a tendency to parallel arrangement in the felspars; a typical syenite.

130. *Biotite-granulite.*—An aggregate of quartz, perthite, and red-brown biotite, showing a granulitic structure. Some large crystals of felspar have a somewhat porphyritic tendency, but otherwise the structure is even-grained and granular, of the aplitic type. The most noticeable feature is the intense colour of the biotite (lepidomelane), which is quite opaque in the position of maximum absorption.

131. *Hybrid rock* (?).—Large phenocrysts of orthoclase felspar, somewhat rhombic in form and full of inclusions, in a groundmass of very variable texture, composed of quartz, perthite, orthoclase, and green hornblende. In parts the groundmass is granulitic

and micrographic, while in other parts the minerals show the relations characteristic of a dolerite. The specimen also contains a good many pebbles of quartz, with corrosion borders, obviously xenolithic, and it is probable that the whole thing is a mixture rock, composed of alkali-granitic and alkali-doleritic materials. Further material is necessary to elucidate this point.

133 and 134. *Riebeckite-granite.*—A granitic rock of coarse texture, consisting exclusively of quartz, white perthite, and riebeckite. Quartz is very abundant and shows a slight tendency to graphic intergrowth with the felspar. The riebeckite is of a deep prussian blue colour, visible even in the hand-specimen; it forms irregular patches, and occasionally long idiomorphic prisms. The only accessory observed is a small amount of deep purple fluorspar, occasionally visible even in the hand-specimen, but chiefly microscopic.

135. *Riebeckite-pegmatite.*—A small hand specimen associated with the two foregoing, of fairly coarse pegmatitic character, consists of quartz, flesh-red felspar, and large prisms of riebeckite up to two inches in length.

137. *Biotite-aplite Vein.*—This specimen consists of a perthite-granite of fairly coarse texture penetrated by a vein of aplitic character, with red-brown biotite.

138. *Augite-porphyry.*—Phenocrysts of pink and occasionally white felspar in a matrix of quartz, felspar and augite, now represented mainly by some chloritic mineral. The large white felspars, which appear to be albite, have a border of pink orthoclase, and the pink felspars are orthoclase so far as they can be determined: all are considerably decomposed. The groundmass is rather fine in texture, mainly orthoclase in irregular patches with pale green augite, chlorite and a little interstitial quartz, with some opaque iron-ore. This is the hypabyssal facies of a syenitic rock, with dominant potash.

139. *Ægirine-rhyolite.*—A greyish-green rock with very conspicuous flow-structure. It contains phenocrysts of quartz and perthite felspar in a groundmass of variable texture: some bands show a micrographic structure, while others are finely microcrystalline. The minerals of the groundmass are quartz, felspar and ægirine, the latter in small shapeless or elongated grains, with an occasional larger prismatic form: the latter occur chiefly in the coarser bands. No other ferromagnesian minerals were observed.

140. *Graphic Granite.*—The minerals of this specimen are too much decomposed for certain determination. The felspar was probably orthoclase, since no indications of polysynthetic twinning could be seen. The only noticeable feature is the well-marked micrographic structure. There are a few large zircons and a little magnetite.

C.C. 3. *Biotite-granulite.*—A rock of granulitic or aplitic structure, consisting of quartz, microcline, orthoclase, and biotite.

The quartz and felspar are in some parts micrographically intergrown, while elsewhere the structure is granular-hypidiomorphic. The biotite is olive-brown and contains inclusions of allanite with pleochroic halves. This rock appears to be very similar to Nos. 108 and 110, though finer in texture.

C.C. 4. *Topaz-rock.*—This is a specimen of the aplitic rock associated with the tin-tungsten lodes: the actual slice was taken about 1 inch from the edge of a narrow lode of this kind. It consists of quartz, some highly decomposed material representing felspar, topaz, and red and black patches which probably include both iron oxide and wolfram. Quartz, which is very full of bubbles, is the most abundant mineral, followed by topaz. Most of the felspar has completely disappeared, and the specimen is an excellent example of a pneumatolytic topazified rock, allied to greisen in its manner of formation. Cassiterite could not be identified in the slice, though the lodes carry tin.

Conclusions.

The microscopic examination of these specimens confirms in all respects the results arrived at by Major Williams from his field observations. It is quite clear that there are here three types of igneous rock, as follows:—

1. Highly granulitized and crushed granitic gneisses, rich in microcline, with little or no ferromagnesian mineral (103, 109, 111, 112). These appear to be essentially potash granites.

2. Slightly crushed granites intrusive into the above, specially characterized by perthite, riebeckite, and ægirine, and therefore characteristically rich in soda (100, 105, 106, 113, 115). Numbers 108, 110, C.C. 3, C.C. 4 probably belong here. This series contains accessory allanite.

3. A still later series of soda granites, quite free from kataklastic structures, with perthite, riebeckite, and ægirine (124, 125, 133, 134, 135). These are accompanied by smaller intrusions of syenite and a considerable variety of syenite dykes and other small intrusions (101, 102, 120, 121, 122, 123, 129, 138, 139). This series is believed to be of Mesozoic age.

The only basic rock observed (107) is so different from the rest, and so conspicuously fresh and unaltered that it may with some confidence be referred to the Tertiary period.

The first group as here defined corresponds to the older granites of Falconer's classification.[1] The second group are believed to be also of Archæan age, although they appear to have undergone considerably less dynamic metamorphism. It is as yet impossible to state whether any of the hypabyssal types belong to this group. The third group, which may be described collectively as the Ningi series, has evidently undergone much more differentiation, since it includes a large number of dykes and small masses of syenitic

[1] *The Geology and Geography of Northern Nigeria*, London, 1911, chap. iii.

FIG. 1.—The great diamond mine at Sopa, near Diamantina, Minas Geraes, Brazil. Note the excavation in the soft sericitic schist. The surrounding country is hard quartzite.

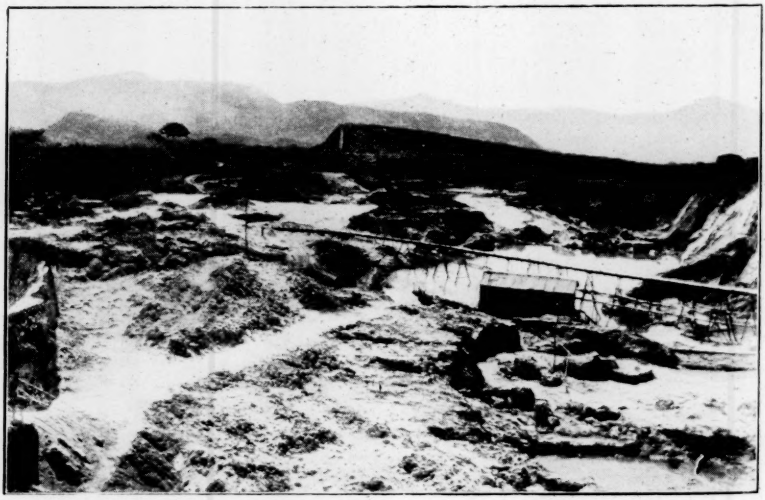

FIG. 2.—The great diamond mine at Bea Vista, near Diamantina, Minas Geraes, Brazil. Note the fissure-like excavation of the mine. The surrounding plateau is formed of hard quartzites.

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composition, and some of the specimens here described as rhyolites show all the characteristics of lava-flows.

From the mineralogical point of view, the most interesting features of the later Archæan and Mesozoic igneous rocks is the dominance of alkaline characters. The felspar is mainly perthite, while the ferromagnesian minerals are chiefly riebeckite and ægirine; the magma was therefore rich in soda; however, no nepheline has been found in the more basic (syenitic types).

Although tin, wolfram, and topaz are abundant in the area, and fluorspar occurs locally, it is remarkable that among these specimens not a single occurrence of tourmaline has been observed. It is evident that the pneumatolytic phase was characterized by fluorine to the exclusion of boron.

The Existence of Diamond-bearing "Pipes" in Brazil.

By Robert R. Walls, M.A., B.Sc.

(PLATE VIII.)

THERE has been great controversy as to whether or not there exist in Brazil diamond-bearing "pipes" such as are found in South Africa. That something of the kind should exist seems to be pretty well acknowledged, but any evidence in support of the discovery of a "pipe" has always been very meagre. The following observations made by the writer on a few mines in the neighbourhood of Diamantina, in the state of Minas Geraes, might be of interest on this somewhat vexed question.

The writer had no practical experience whatever of diamond mines when he arrived in Brazil, and was only drawn into the subject by accident. When studying the sandstones and quartzites of the Serra do Espinhaco he found that in many places these had been "stewed up" as it were and metamorphosed into rock crystal. There was no sign of a granite or aplite intrusion in the neighbourhood, but these crystal formations all lay close to the great diamond mine at Sopa, and from the field evidence alone it seemed as if this latter must have been an igneous intrusion.

The rocks of the district are all hard quartzites, remarkable for the horizontality and regularity of their bedding. The great mine takes the form of a fissure, a mile or more in length, and seems to run down vertically through the bedded quartzites, although the actual contact was nowhere exposed. This pipe or fissure is filled with a sericitic schist crowded with small crystals and concretions of iron-ores. It is green in colour, and so soft that it can be easily broken down with wooden spades and bateas. This green earth is then washed by negro labour, and the iron-ores and diamonds are left as a heavy residue. The green earth bleaches to a white clay, and is found all down the streams mingled with quartz sand. The Sopa mine lies on the very summit of the ridge of the Serra do Espinhaco, and the streams which run down from it are

diamantiferous for hundreds of miles. Many important placer mines are worked in the beds of these rivers.

The field evidence therefore—the long fissure in the quartzites and the trail of diamonds from thence to the sea—seems to indicate that this was a pipe of igneous origin and the original home of the diamonds. But the sericitic schist with its concretions and crystals of iron-ores which fills the fissure differs considerably from the Kimberlite of the South African mines. Unfortunately also Brazilian geologists of considerable standing have contended for so long that there were no pipes in Brazil equivalent to the Kimberlite pipes of South Africa that to establish the fact of their existence will require much more evidence on the general geology of the district.

Besides Sopa two other mines on the summit of the Serra do Espinhaco exhibit the phenomena of pipes. One of these lies at Boa Vista, some 20 or 30 miles south-east of Sopa. The writer visited this mine and found it being worked under the direction of Mr. Draper, an engineer who had had considerable experience in the pipes of South Africa and who recognized this as an igneous pipe, though highly metamorphosed. The aspects of these two mines are shown on the accompanying plate, where they are seen as long fissures surrounded by the hard horizontally bedded quartzites. The third mine at Sao Joao de Chapada lies about 15 miles north of Sopa, and though the writer did not visit it he was assured by miners who had worked there that it was exactly similar to the mine at Sopa. These three mines occur in separate and distinct outcrops of sericitic schist, and the intervening country is covered entirely by the quartzites. These quartzites appear to be of considerable thickness in the neighbourhood of Diamantina and to lie directly on the crystalline complex.

The geology of the diamond region of Bahia farther north on the Serra do Espinhaco is now pretty well known owing to the researches of Derby, Branner, and Crandell. The following strata counting from below upwards have been mapped there:—

9. Recent formations.
8. Salitre Series.
7. Estancia Series.
6. Lavras Series.
5. Paraguassu Series.
4. Jacuipe Flints and Caboclo Shales.
3. Tombador Series
2. Jacobina Series.
1. Crystalline Complex.

With the exception of the first of these they are all sedimentary deposits. The Lavras series is the one which contains the principal diamond mines, and the inference is, therefore, that the diamonds have been obtained from the disintegration of older rocks. This only leaves us five series of strata with their contemporaneous igneous intrusions. Again the general evidence seems to point to the fact that the drainage has always been as at present from the south or

FIG. 1.

FIG. 2.

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from what the writer calls the high plateau of south-east Brazil. This would indicate that the diamonds now found in the Lavras series in Bahia had their origin in an igneous rock somewhere in the high plateau to the south. Carrying the inference still further we might assume that the sudden appearance of the diamonds in the Lavras series and their absence from earlier strata (which seems to be the summary of the evidence of Derby, Branner, and Crandell) would indicate the formation of the diamond in an igneous rock of later Paraguassu age. The weathering of an intrusive rock of this period would then give rise to the diamond-bearing Lavras series.

The quartzites of the Diamantina region in Minas Geraes are supposed to be contemporaneous with the Jacobina series of Bahia. The overlying strata have been removed by denudation. If the assumed pipes of Sopa, Boa Vista, and elsewhere are of late Paraguassu age there must have been considerable erosion with removal of their diamond contents. This would certainly account for the rich deposits in sedimentary rocks lying to the north. The present sections are the deep-seated remnants of pipes which no doubt towered above their present sites for many hundreds or even thousands of feet.

All the above-mentioned rocks, with the exception of group 9, are of early Palæozoic age, and have been highly metamorphosed. Whether the sericitic schist of Sopa is the metamorphosed remnant of an igneous intrusion, and, if so, by what chemical process it has been so metamorphosed is a question for the geological chemist. The commercial aspect of the question, the discovery of the original home of the diamond which has scattered its wealth over such great areas of sedimentary rock in Brazil, would certainly warrant a closer investigation into the subject.

The Metamorphism of the Pre-Cambrian Dolomites of Southern Eyre Peninsula, South Australia.

By C. E. Tilley, B.Sc., A.I.C., Emmanuel College, Cambridge.

(PLATE IX.)

Introduction.
The Hutchison Series
Dolomites of the Hutchison Series.
(*a*) The Sleaford Bay Section.
(*b*) Dolomites of the Hutchison Area.
Chemical Changes involved in Metamorphism.
The Calc-magnesian Silicate Rocks of the Hutchison Series.
(*a*) Diopside Rocks.
(*b*) Diopside Microcline Rocks.
The Chemistry of the Development of the Calc-magnesian Silicate Rocks.
Conclusion.

Introduction.

THE basement platform of Southern Eyre Peninsula consists of a series of igneous and metamorphic rocks of pre-Cambrian age. Rising from beneath the Mesozoic and Tertiary strata of the

Nullarbor plains, they may be regarded as a south-easterly prolongation of the great pre-Cambrian Shield of Western Australia. The platform is for the most part within a few hundred feet of sea-level, and large areas of the region are covered by the products of long-continued weathering of the older rocks or by siliceous deposits of late Tertiary age. The best sections for geological study are those exposed along the coastline, and in the hilly areas of Hutchison and Warrow.

The general discussion of the sequence of the pre-Cambrian in this area will be reserved for another place, and this paper will be limited to a description of certain metamorphosed sediments embraced within the oldest group of rocks that have been recognized, and which it is proposed to designate the Hutchison series.

Hutchison Series.

Only remnants of this terrain are now exposed to view, the series having been broken up by the great intrusions of igneous gneisses that succeeded. To this group of igneous rocks, the name—Flinders series—is given, from the hundred and county in which they attain a widespread and typical development. Fragments of the Hutchison beds have been engulfed in the Flinders gneisses, and these can be recognized at points remote from typical exposures of the Hutchison series. There is abundant evidence that this sedimentary terrain has been invaded and intensely metamorphosed by the succeeding igneous intrusions. The best exposures of the Hutchison series are developed along the coast of Sleaford Bay, and in the hundred of Hutchison in the hilly district west of Tumby Bay. At various intermediate points between the Sleaford Bay and Hutchison areas, these rocks emerge from beneath a mantle of weathered products, but no extensive unweathered outcrops have as yet been recognized. In a north-easterly direction in the county of Jervois, R. L. Jack has described dolomites associated with schists and gneisses, and doubtless these rocks represent the same series along the same line of strike. Undoubtedly the best exposures of these rocks are those outcropping on the shores of Sleaford Bay, near Sleaford mere. Here in a section of less than half a mile a most complex series of sediments is found, penetrated by granites and pegmatites of the Flinders series.

The beds, now exposed in a highly metamorphosed condition, comprise mica schists, garnet gneisses, graphite schists, graphite garnet gneisses, quartzites, dolomites, and calc-magnesian silicate rocks. The beds strike in a north–south direction, with a high angle of dip to the west (75 degrees) to vertical. Subsidiary folding and faulting have been observed. On the west they are bounded by granites and gneisses of the Flinders series, while on the east the beds disappear beneath calcareous sand rock and travertine, which here forms the coastline till the igneous rocks of Flinders intervene, near the Curta Isles, across the Bay.

In the Hutchison area the same types of metamorphosed sediments are to be found, but here the dolomites are more conspicuous, and calc-magnesian silicate rock do not form as important a feature as in the southern outcrops.

In the accompanying diagrammatic section (Fig. 1), the relations of the dolomite and diopside rocks are shown for the Sleaford Bay area. Only part of the Hutchison series exposed along the shore-line has been represented in this section, nor are all the diopside rocks revealed, there being a further development in a continuation of the section eastward.

SECTION ALONG THE SHORE AT SLEAFORD BAY.

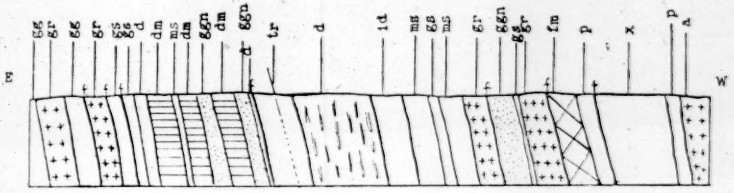

FIG. 1.

← — — — — — — — 500 yards — — — — — — — →

a = Flinders gneiss.
p = pegmatite.
gr = granite.
f = ironstone band.
fm = forsterite marble.
gs = graphite schist.
ggn = garnet gneiss.
x = no exposure.
dm = diopside-microcline rocks.
d = diopside rock with quartz veins.
id = impure diopside rocks with micaceous bands.
tr = transition beds containing diopside, highly silicified, with fault breccia of silicified quartz rock.
gg = garnet-graphite gneiss.
ms = mica schists.

(Thickness of individual beds not to scale.)

Some of the exposures are badly weathered, and in some cases outcrops are missing, so that the succession cannot claim detailed accuracy.

Quartz veins from the neighbouring granites are often very abundant in the diopside rocks, and pegmatite veins are present, more especially in the graphite and garnet rocks. These rocks are, however, outside the scope of the present inquiry.

THE DOLOMITES OF THE HUTCHISON SERIES.

Dolomites form an important group of rocks of the Hutchison series. They range from practically pure dolomites to calc-magnesian silicate rocks, in which all traces of carbon dioxide have been removed. The evidences of all these rocks show that the pre-existing sediments were true dolomites or highly dolomitic limestones. Dealing now with those less impure types in which a carbonate mineral has been retained, we shall endeavour to describe their characteristics under the grouping of those developed at Sleaford Bay and those occurring in the Hutchison area.

(*a*) *The Sleaford Bay Section.*

The dolomites of the Sleaford Bay area are limited to a comparatively small exposure on the shore-line. Here they are associated with schists and gneisses intruded by pegmatites and granites in sill-like fashion.

As exposed on the beach, the marble outcrop is bounded on the east by a sill of hornblende granite and on the west by a coarse pegmatite. At its border it is replaced by ironstone. The exact thickness cannot be made out owing to the poorness of exposures, and large blocks evidently not in situ are present on the beach near at hand. When fresh it is a compact, cream-coloured rock, but on weathering its composite character is indicated by the selective weathering, the calcite, dolomite, and new-formed silicates being attacked differentially, leading to hollows and projections, the latter consisting mainly of dolomite with unaltered silicates. Thin sections of these rocks when examined under the microscope show an interesting suite of minerals, which include calcite, dolomite, forsterite, and an amphibole of the edenite-pargasite group. Rarely phlogopite and diopside may be seen.

Dealing with these minerals we have :—

(i) *Calcite.*—Abundantly present in rounded grains up to 1·5 mm. in size. Cleavages are usually present and twinning lamellæ (on the plane 0112) are rarely to be observed. In sections which show the rhombohedral cleavages intersecting at the cleavage angle of 74 degrees the twinning lamellæ are seen to intersect the acute angle between the cleavages, and are parallel to the longer diagonal of the rhombohedron.

The distinction between calcite and dolomite was primarily effected by using Lemberg's solutions. Uncovered sections were treated with a dilute solution of ferric chloride for two minutes, washed and then immersed in ammonium sulphide solution, washed and finally treated with potassium ferricyanide, by which the precipitated ferrous sulphide is converted into Turnbull's blue. By this means calcite is stained blue, whilst dolomite remains unstained. This method has been found very satisfactory in differentiating these carbonates. The calcite grains in these rocks are remarkable for their turbidity and the dolomite for its limpidity. The clouded character is due to minute inclusions, some of which are transparent and of high refractive index. They are often quite ragged in outline, and appear not to be disposed along any particular direction. Others, usually more minute, are opaque, and their nature is not clear. In some calcite grains there are small granules of dolomite, clear and unstained, suggestive of a ramifying intergrowth. In one slice (115*a*) a primary twin of calcite-twin plane—(1011)—is shown, the two parts having their vertical axes inclined at approximately 90 degrees, and the twin being bounded by prism and rhombohedron faces.

(ii) *Dolomite.*—As remarked above, this mineral has been distinguished by its unstained character when the section is treated with Lemberg's solution. Whenever it shows any definite outline, this outline is always idioblastic towards calcite, the reverse not being seen. The marked limpidity is a notable feature. Contrary to the usual statements in the literature, the dolomite in these slides is characteristically twinned, often showing rather wide hemitrope bands. In fact, it may be said that dolomite is more often twinned than calcite. The twinning law seems also to be of a different type to that of calcite. The plane $01\bar{1}2$ in dolomite is not a glide plane, and the twinning in these slides would correspond to twins on $02\bar{2}1$. Where a section shows the two cleavages intersecting at the rhombohedral angle, the twin bands intersect the obtuse angle between the cleavages and are parallel to the shorter diagonal of the rhomb. This point serves to distinguish it from calcite. In addition, then, to the staining differentiation for these rocks, we can apply the following criteria :—

(1) Twinning in dolomite is at least as common as in calcite, and is often more so. Moreover, the twinning is of a different type. In dolomite the twin plane is 0221, and in calcite 0112. In favourable sections, such as those showing the cleavages intersecting at the rhombohedral angle, the lamellæ cut the intercleavage angle, such that in dolomite they are usually parallel to the shorter diagonal of the rhomb, and in calcite are parallel to the longer diagonal. The twinning in dolomite would appear to indicate that the plane 0221 is also a glide plane.

(2) Where the one mineral exerts its form against the other dolomite is always the idioblastic mineral.

(3) Dolomite is usually of a remarkably limpid character, whilst calcite is invariably turbid, owing to the presence of minute inclusions. The significance of this will be dealt with later. This feature can be safely used to differentiate calcite and dolomite in the rocks under discussion, and is the most important of the three criteria.

(iii) *Forsterite.*—Builds rounded grains or crystals with elongation parallel to the *c* axis in size up to 1·5 mm., rarely larger. In some grains the 010 cleavage, the trace being parallel to the elongation, is very distinct, but it may be completely absent. Apart from its characteristic decomposition products, it is distinguished by its large optic axial angle, positive sign, and the position of the optic axial plane with reference to the 010 cleavage. The characteristic cracks and the serpentinous decomposition parallel the occurrence of its ferriferous member in the eruptive rocks. In some sections (115) the forsterite is now represented by aggregates of opal and calcite. The determination of calcite within the forsterite outline was settled by a staining test.

(iv) *Edenite.*—This is a clear, colourless mineral, idioblastic, with a moderate refractive index, which occurs sparingly in these rocks, embedded in calcite or dolomite.

Several sections show the typical amphibole cross-section cleavages intersecting at an angle of 124 degrees. The crystals are optically positive, and extinctions of 25 degrees have been observed. These properties do not correspond with those of ordinary tremolite. Moreover, a basal section yields only a very low interference colour, and in convergent light such sections are seen to be almost normal to an optic axis. The optic axial angle is not large, and the plane of the optic axes bisects the obtuse intercleavage angle as in normal amphiboles. These characters serve to identify the mineral as a member of the edenite-pargasite series. If we restrict the name edenite to the colourless members of this group, then this mineral must be classed as edenite.

Kreutz [1] has described a pargasite, from Pargas, Finland, containing 10·83 per cent Al_2O_3, 1·56 per cent FeO, 0·76 per cent Fe_2O_3.

The optical properties are given as R.I. = 1·62, D.R. = ·0195, optically positive, 2V = 59 degrees, $Z \wedge c = 27$ degrees.

W. E. Ford,[2] in an optical study of the amphiboles, describes an edenite from Grenville township, Canada, containing 11·37 per cent Al_2O_3, FeO=0·42, Fe_2O_3=0·42. The double refraction approximated ·020, optically positive, 2V = 56 degrees, and the extinction $Z \wedge c = 29$ degrees.

Coomaraswamy,[3] in describing the crystalline limestones of Ceylon, gives the analysis of an aluminous tremolite, $Al_2O_3 = 13·76$. The optical properties are not given, but material from another locality gave extinctions on 110 cleavage flakes of 17 degrees, which would approximate the edenite values on 010.

In view of these descriptions, and the parallelism of the optical properties of the material in those dolomites, with those described for the edenites by Kreutz and Ford, we can have little doubt in assigning this mineral to the edenite group.

Unfortunately the material at disposal and the comparative scarcity of the mineral in the rock, has not enabled a chemical analysis to be made. Some sections, cut parallel to the vertical axis showing a single cleavage, are with difficulty distinguishable from colourless diopside, the optical orientation of which is closely similar.

(v) *Alteration Products of Forsterite.*—Forsterite is, as has been noted, usually in part, or wholly replaced by other minerals, amongst which serpentine, calcite, rarely dolomite or magnesite, and opal are the chief.

Serpentine may be developed to the exclusion of the carbonates or opal. Calcite has been definitely proved in certain cases, and a few

[1] S. Kreutz, Min. Mitt., vol. xxvii, 1908, p. 249.
[2] W. E. Ford, Amer. Journ. Sci., vol. xxxvii, 1914, p. 179.
[3] A. K. Coomaraswamy, Quart. Journ. Geol. Soc., vol. lviii, 1902, p. 417.

unstained grains in certain of the pseudomorphs indicate dolomite or even magnesite, the distinction between these two minerals not being possible.

(115) is a good example of the replacement by opal and calcite. The opal generally forms a border to the pseudomorph, and by its extension across the grain often separates the calcite into isolated grains. The relative positions of forsterite with regard to calcite and dolomite call for remark.

An examination of the slides shows that in the great majority of cases the forsterite is embedded in calcite. In almost all cases there is present some calcite abutting forsterite crystals.

(*b*) *Dolomites of the Hutchison Area.*

The dolomites of the Hutchison area are well developed in the hilly district behind Tumby Bay, and good exposures are met with in the gorge of the Mine creek.

Serpentinous marbles outcrop in the north-eastern corner of section 63 in the hundred of Hutchison, and are here striking east with an almost vertical dip. Marbles are again met with near the Copperinga mine in section 804. Here serpentine occurs in bands and lenses through the rock. In a tributary stream—the Waterfall Creek—the marble makes a prominent cliff-face with a large angle of dip, and striking approximately north-east. A drive into the side of the hill shows veins of chrysotile asbestos up to half an inch in width. The associated rocks are garnet gneisses. On the west the marbles are bounded by mica schists and pegmatized schistose rocks. Graphite has been observed in these schists. The whole series has been invaded by the granite gneisses, which have their best development in the Mine Creek to the east. These rocks present the same characteristics as those at Sleaford Bay, and represent the same series of sediments now highly metamorphosed.

To the north-east, in the adjoining county of Jervois, R. L. Jack [1] has noted crystalline dolomites, associated with quartzites, schists, and gneisses in the hundreds of Dixon and Miltalie. These rocks outcrop along the strike extension of the "graphite line" in the county of Flinders. No detailed petrological examination of these dolomites is reported, but Jack indicates the presence of forsterite, tremolite, and diopside.

Analyses of three dolomites from different localities in this area show a range of the CaO/MgO ratio from 1·0 to 1·9. The series has been invaded by granitic and pegmatitic intrusions.

In addition to the minerals found in the Sleaford Bay exposures, there are rocks in this district containing spinel, phlogopite, apatite, diopside, chrysotile-asbestos, talc, and magnetite. Some of the dolomites are now represented by ophicalcites, in which dolomite is only sparingly present, and may be absent. There has in these

[1] R. L. Jack, Bull. No. 3 Geol. Surv. S. Austr., 1914, pp. 11–12.

cases been sufficient detrital silica to combine with all magnesia to form forsterite.

Dealing with these minerals we have:—

(i) *Spinel.*—This mineral is characteristically of a light-green tint, building little rounded grains or more rarely idioblastic. The green coloration is to be ascribed to ferrous iron, indicating a member of the pleonaste group. It may be present isolated in calcite or dolomite, and also abutting or enclosed in original forsterite grains, which now consist of forsterite residues surrounded by serpentine. In some examples the spinel is bordered by a thin ring of serpentine, presumably derived from it. Marbles containing abundant light-green spinel are well developed in the north-eastern corner of section 63, hundred of Hutchison.

(ii) *Phlogopite.*—This is an important constituent of the marbles of this area. It is colourless to a very light brown, and is often much bent and contorted. Cleavage-flakes give an interference figure normal to an acute bisectrix, but the optic axial angle is so small that the opening of the hyperbolæ is very slight. It shows peripheral and intercleavage alteration to a chloritic product.

(iii) *Apatite.*—Is developed in little rounded to sub-hexagonal grains, showing uniaxial negative character. It is commonly associated with rocks in which phlogopite is present.

(iv) *Chrysotile-Asbestos.*—Occurs in irregular veinlets in yellow-green serpentine in the gorge of the Mine Creek. The fibres are always elongated at right angles to the length of the veins.

Under the microscope the asbestos is seen to be present in anastomosing veins, cutting across the mass of serpentine. The refractive index is less than that of C. balsam. It is optically positive, and the optic axial plane is parallel to the length of the fibres. The elongation is positive and the extinction is straight.

(v) *Diopside.*—Occurring in the same marble are nodular masses of green diopside, associated with vein quartz, to which the formation of diopside is due. Where the quartz vein has penetrated the dolomite it is surrounded by a ring of the green silicate. The pyroxene has not been definitely found in this locality other than with this association, but in other places it occurs as a normal product of metamorphism not involving addition of material.

(vi) *Forsterite.*—The serpentinization of the olivine of these rocks is accompanied by a separation of magnetite granules at the borders of the pseudomorphs and betrays the original presence of a ferriferous forsterite. There must still be considerable iron present in some of the serpentine, judging by the strength of colour that is developed (328). In other cases the forsterite is clear and unaltered (290).

Hæmatite may take the place of magnetite bordering serpentine pseudomorphs (313).

In the absence of silica the rock has recrystallized without change. No. 307, from an outcrop in section 804 treated with Lemberg's solution, remained unstained with the exception of a very small

amount of calcite. The specific gravity is in conformity with this determination, being 2·84. There are a few flakes of phlogopite and a few grains of an amphibole, possibly edenite.

Nodular masses of yellow-green serpentine are present in a zone of the same outcrop up to 2 inches in diameter, and occasionally larger masses are met with. It is with these that the chrysotile veins are associated. The specific gravity of homogeneous fragments of the serpentine varied from 2·55 to 2·56. The specific gravity of the ophicalcite rocks is close to 2·70, and vary from 2·69 to 2·72. This can be ascribed to a changing distribution of serpentine and concurrently the coming in of dolomite.

Chemical Changes involved in Metamorphism.

The mineralogical features of this suite of rocks are those characteristic of metamorphism of the thermal type, and there is no evidence that shearing stress has played any important rôle. In the rocks under discussion we can also exclude magmatic additions as being inoperative, with the possible exception of such a volatile constituent as water. It is clear that apart from detrital impurities, like silica and alumina, the sediments were true dolomites or dolomitic limestones, with a high percentage of magnesia. As to the origin of the dolomitization it is clearly anterior to this epoch of metamorphism, and there seems little reason to doubt that it is the result of metasomatic processes subsequent to the deposition of the rocks. At the time of metamorphism we can safely assume that they were dolomitic sediments with a certain amount of silica and alumina of detrital origin. In the first place, the chemical changes involved have been the elimination of carbon dioxide in so far as this has been possible by reactions, involving the material of detrital origin. In the absence of such reactions there has been a re-crystallization of the carbonate minerals. In no case has the simple decarbonation of the magnesite molecule of dolomite taken place to periclase. It is to be inferred that at the temperature prevailing the pressure was in excess of that necessary to effect any appreciable disruption of the dolomite molecule, in the absence of silica or alumina.

At a given pressure the temperature of decomposition must be considerably lower for dolomite in the presence of silica or alumina. In these rocks reactions involving these constituents have proceeded to completion. The reactions involved bring out very clearly the greater chemical reactivity of magnesia as compared with lime, a point which is, of course, the basis of Teall's dedolomitization principle. Dominant lime-bearing minerals, as the garnets, vesuvianite, wollastonite, etc., are conspicuous by their absence, and when they do appear it is usually after all magnesia has been satisfied. For example, scapolite and bytownite appear in associated rocks originally so impure that their metamorphism is accompanied by complete elimination of carbon dioxide. These

lime-bearing minerals are sufficiently familiar in the metamorphism of the calcareous limestones.

The production of forsterite from dolomite involves the simultaneous formation of calcite, as indeed does the formation of all the minerals involved in these rocks, with the exception of a non-aluminous diopside. The equations representing the production of forsterite, edenite, and diopside are shown below.

(1) $2\,\underset{\text{dolomite}}{CaMg(CO_3)_2} + \underset{\text{quartz}}{SiO_2} = \underset{\text{forsterite}}{Mg_2SiO_4} + 2\,\underset{\text{calcite}}{CaCO_3} + 2\,CO_2$

(2) $3n + 2\,\underset{\text{dolomite}}{(CaMg(CO_3)_2)} + 4n + 3\,(SiO_2) + Al_2O_3$
$= n\,\underset{\text{edenite}}{CaMg_3(SiO_3)_4 + CaMg_2Al_2(SiO_4)_3} + 2n + 1\,\underset{\text{calcite}}{(CaCO_3)} + 4n + 3\,(CO_2)$

(3) $\underset{\text{dolomite}}{CaMg(CO_3)_2} + 2\,SiO_2 = \underset{\text{diopside}}{CaMg(SiO_3)_2} + 2\,CO_2$

The ratio $R = \dfrac{SiO_2 + Al_2O_3}{CaO + MgO}$ becomes an important criterion in the formation of these minerals.[1] Considering the case where alumina is zero, the production of forsterite, tremolite, and diopside is conditioned by the value of R, being $\frac{1}{4}$, $\frac{2}{3}$, and 1 for these minerals respectively. For the aluminous amphibole-edenite R becomes $\dfrac{2n+2}{3n+2}$, where n is the ratio of tremolite molecules to Scharizer molecules. In the presence of increasing silica, forsterite gives place to first tremolite, and then diopside, and this order is one of decreasing dedolomitization. The formation of any one of these minerals can be regarded as dependent on the amount of silica present (i.e. R) in thermal metamorphism, or the amount of dolomite involved within the sphere of diffusion of silica.

The presence of alumina in the absence of silica, possibly as bauxite leads to the formation of spinel as represented in the equation

$$CaMg(CO_3)_2 + Al_2O_3 = \underset{\text{spinel}}{MgAl_2O_4} + CaCO_3 + CO_2.$$

When silica is present the spinel may accompany forsterite, and the close association of spinel and forsterite as seen in the thin slices,—spinel often present within the boundaries of forsterite, or abutting forsterite grains, is evidence of co-crystallization in accordance with the equation

$$3\,CaMg(CO_3)_2 + SiO_2 + Al_2O_3 = Mg_2SiO_4 + MgAl_2O_4 + 3\,CaCO_3 + 3\,CO_2.$$

The value of R is here $\frac{1}{3}$.

Apparently when R exceeds this value, spinel is less often formed,

[1] Or in general for magnesian limestones, $R = \left(\dfrac{SiO_2 + Al_2O_3}{MgO}\right)$, with the modified R values for these minerals.

and alumina enters the amphibole or pyroxene molecule which arises in this case.

So much can be gathered from an inspection of the rocks under discussion. The associations tremolite–spinel, diopside–spinel are not to be seen in the slides.

That alumina is absorbed into the silicate molecule is abundantly confirmed by the presence of the aluminous tremolite, edenite. The presence of possible alumina in the diopside is not so easily made evident by optical determinations.[1]

It seems reasonable to conclude that forsterite and spinel occur together with a value of R equal to one-third, and that when this value is exceeded spinel does not form, and the alumina is absorbed in the metasilicate molecule in accordance with the excess silica either in amphibole or in pyroxene. If spinel is found associated with the metasilicate, it indicates that the original distribution of the detrital materials in the rock was such that they were not involved within a common sphere of diffusion, that is, part was without the radius of diffusion of the remainder, and thus a limiting value of the amplitude of diffusion in thermal metamorphism might be thereby established.

Coming now to the more complex mineral phlogopite, its formation is to be ascribed to the same period of metamorphism, but the detrital materials were in this case of somewhat different nature. The potash and alumina are doubtless derived from detrital sericite present in the original sediment.

Accepting F. W. Clarke's views of the constitution of the micas,[2] we may write phlogopite as $H_2KMg_3Al(SiO_4)_3$, and the following equation may represent its formation, when it is accompanied by spinel, as is often the case in the rocks under discussion :—

$$\underset{\text{dolomite}}{4\,CaMg(CO_3)_2} + \underset{\text{sericite}}{H_2KAl_3(SiO_4)_3} = \underset{\text{phlogopite}}{H_2KMg_3Al(SiO_4)_3} + \underset{\text{spinel}}{MgAl_2O_4} + \underset{\text{calcite}}{4\,CaCO_3} + 4\,CO_2$$

In some rocks, however, this mineral is not accompanied by spinel, and the above equation cannot represent the formation of phlogopite in these cases. To produce phlogopite of this composition alone, requires dolomite to interact with the oxides $K_2O : Al_2O_3 : SiO_2$, in the ratio 1.1.6, or the proportions present in felspar. This mineral, however, is unlikely to be present in any original dolomitic sediment, representing the mature weathering product of pre-existing rock-masses. The ultimate derivation of phlogopite in these rocks must be ascribed to detrital sericite, and there is no reason to infer that there has been an addition of magmatic material other than the purely volatile agents, water and hydrofluoric acid. By adjusting the relative amounts of the isomorphous elements,

[1] According to V. Schumoff-Deleano (Centr. Min., 1917, p. 290) diopside can take up 15 per cent Al_2O_3 in solid solution.

[2] F. W. Clarke, Bull. U.S.G.S., No. 616, 1916, p. 393.

H and K, in the phlogopite constitution, we may represent its formation by the succeeding equation

$$\underset{\text{dolomite}}{9\ CaMg(CO_3)_2} + \underset{\text{sericite}}{H_2KAl_3(SiO_4)_3} + \underset{\text{quartz}}{6\ SiO_2} + 3\ H_2O = \underset{\substack{H_2KMg_3Al(SiO_4)_3 \\ \text{phlogopite}}}{2\ H_3Mg_3Al(SiO_4)_3} + \underset{\text{calcite}}{9\ CaCO_3} + 9\ CO_2$$

Hydrofluoric acid being regarded as an essential constituent of phlogopite, this will replace some of the water in the left-hand side of the equation, entering the phlogopite molecule as the univalent radicle, MgF, isomorphous with H and K.

Whatever equation is adduced for the formation of phlogopite, calcite is inevitably a by-product of the reaction, and phlogopite must therefore be added to the group of minerals which induce by their formation dedolomitization.

Apatite is doubtless derived by the recrystallization of original phosphate substance in the sediment, possibly of organic origin or of detrital apatite of pre-existing rocks.

The apatite is observed to be plentiful in those rocks in which phlogopite is most abundant, and this association may have been accentuated through the agency of fluorine.

The presence of calcite as a constituent of decomposed forsterite grains calls for some remark.

The changes which have operated since the formation of forsterite are firstly its replacement by serpentine, with or without the separation of magnetite, and this may be represented by the equation

$$2\ Mg_2SiO_4 + 2\ H_2O + CO_2 = H_4Mg_3Si_2O_9 + MgCO_3$$

The magnesium carbonate is either removed in solution or is absorbed into the calcite or dolomite molecule during this change. The change has in many cases proceeded further, however, and in the dolomites of Sleaford Bay serpentine has yielded pseudomorphs of opal and calcite.

$$H_4Mg_3Si_2O_9 + 3\ CO_2 = \underset{\text{opal}}{2\ SiO_2} + 3\ MgCO_3 + 2\ H_2O$$

Here, again, magnesite is released, and although this may be present in some of the pseudomorphs, yet in the majority its place is taken by calcite.

The origin of the magnesite so characteristically associated with the graphite schists in the vicinity, and developed in large masses in the northern area, and essentially of secondary origin, can probably be traced in part to those reactions which have ultimately resulted in the degradation of forsterite to opal and calcite.

The conversion of the compact serpentine into the fibrous chrysotile asbestos is apparently a recrystallization in situ, under conditions of non-uniform pressure, in which case the veins represent potential fractures, the elongation of the resulting chrysotile fibres being normal to the direction of maximum pressure.

It can be considered that the veins have arisen as a consequence of the stress set up during the hydration by probably meteoric waters of the original forsterite to compact serpentine. Potential fractures arising through this agency, the minute fibres of heterogeneous orientation, are subject to an active unequal pressure in the vicinity of the points of potential fractures, such that in recrystallizing solution takes place in those fibres oriented across the direction of minimum pressure, only to be redeposited on those fibres whose elongation is parallel to the direction of minimum pressure, uniform cross fibre veins thus arising.

The relationship of the new-formed calcite to forsterite.

Teall,[1] first pointed out that forsterite formed during metamorphism was intimately associated with the new-formed calcite and usually in direct contact. It has already been remarked that the same features are to be seen in the rocks under discussion, and in many cases the association is very striking. The forsterite may be wholly embedded in calcite or partly surrounded by an aureole of this mineral. Crook[2] has pointed out that in many examples of forsterite marble studied by him the silicate is separated from the calcite by a thin ring of dolomite. No cases of this nature have been found in these marbles. The distribution of dolomite, calcite, and forsterite is often best seen by staining a thick slice of the rock and then covering with a cover-glass. The individual grains can then be easily made out with a lens.

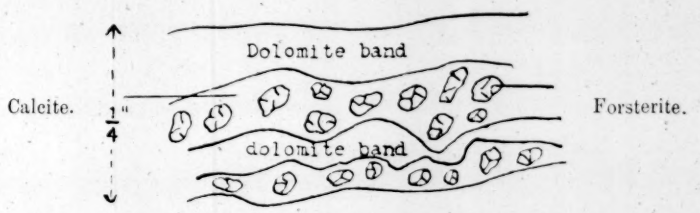

FIG. 2.—Diagrammatic sketch of portion of a flat surface of dolomite.

A dolomite from the Hutchison area treated in this way was seen to consist of bands of unstained dolomite, alternating with a band in which the forsterite grains are concentrated, and of calcite (see Fig.2). This appears to afford evidence that we have here to deal with bands of originally differing composition, viz. dolomite bands free from impurities and containing detrital silica respectively. As a result of the formation of forsterite, the siliceous band is dedolomitized, the newly formed forsterite being surrounded by recrystallized calcite derived from the reaction. These examples serve to confirm the view that the radius of diffusion in thermal metamorphism is confined within comparatively narrow limits.

[1] J. J. H. Teall, GEOL. MAG., 1903, pp. 513–14.
[2] T. Crook, GEOL. MAG., 1911, pp. 339–45.

The occurrence of small grains of spinel embedded in dolomite without proximity to calcite may perhaps be explained by assuming that the new-formed calcite is completely absorbed within the dolomite molecule—the evidence pointing to the view that there is a limited miscibility of these two minerals, conforming, presumably, to Type 5 of Roozeboom's classification.[1]

The criteria for the distinction of dolomite and calcite.

The three criteria which are available for the distinction of dolomite and calcite in some of these rocks have already been mentioned. Of these the most important is the distinction based on the turbidity of the new formed calcite. The dolomite, on the other hand, is remarkable for its clarity and limpid character. The turbidity of the calcite, when examined under the high power, is seen to be related to the presence of minute inclusions of two types, one colourless to greyish particles of high refractive index, and certain opaque particles of uncertain nature, but perhaps carbonaceous. However this may be, it is evident that the turbidity is of general occurrence. Some of the particles may be of detrital origin, and their presence in calcite and absence in dolomite may stand related to the position of these minerals in the crystalloblastic series.

Dolomite is the stronger mineral, and is usually idioblastic towards calcite. During recrystallization foreign material may be discharged, only to be absorbed within the weaker and more yielding calcite.

All these criteria are to be found in the literature on the constitution of the crystalline limestones, but the data are somewhat confusing. The criteria as noticed here are somewhat similar to those advanced by Lacroix [2] for the limestones of Ceylon, and later by Fermor [3] for the crystalline limestones of the Chhindwara district, India.

Some of them are diametrically opposed to the criteria summarized by Renard,[4] and reprinted in the textbooks. Fermor would explain his own examples (apparently as abnormal), and presumably those of Lacroix, by the suggestion that the carbonates have been formed direct from silicates, and not by the alteration of pre-existing calcite. Whilst it is true that the carbonates in the rocks under discussion have been recrystallized, there is not the slightest evidence that this silicate derivation obtains. They are recrystallization products under the influence of thermal metamorphism, the majority of the calcite being released from original dolomite molecules.

(*To be continued.*)

[1] R. C. Wallace, Compte-Rendu XII[e] session Congrès Géologique International, Canada, 1913, pp. 882–3.

[2] M. Lacroix, Rec. Geol. Surv. India, vol. xxiv, 1891, pt. iii, pp. 191–2.

[3] L. L. Fermor, ibid., vol. xxxiii, 1906, pt. iii, pp. 195–7.

[4] A. F. Renard, Bull. Acad. Royale de Belgique, vol. xlvii, 1879, No. 5, p. 557.

On the Investigation of the Mechanical Constitution of Loose Arenaceous Sediments by the method of Elutriation, with special reference to the Thanet Beds of the Southern Side of the London Basin.

By Herbert Arthur Baker, M.Sc., F.G.S.

(*Concluded from p. 420.*)

Velocities of the Currents from which the Thanet Beds were deposited.

THE speeds of the currents employed in the elutriation process in sorting diversely sized material bear no relation whatever to the speeds of the currents, which are competent to transport the same material. The elutriation process in no way imitates the natural processes whereby sediments are transported, sorted, and deposited. The determination of competent velocities in relation to size of material transported is quite a distinct investigation, and one which still calls for much study in spite of the time and attention given to it by numerous workers.

A conclusion which appears to be very generally held is that the diameter of the largest particle a current can move is proportional to the square of the velocity. This is the conclusion to which the theory of impact and transport by a current leads, and results obtained by a large number of investigators appear to endorse it. The law may be stated in the form :—

$$d = kV_c^2$$

where d = diameter of largest particle transported,

k = a constant,

and V_c = the speed of the current which is just competent to transport the particle.

Difficulty arises, however, as soon as we endeavour to assign a definite value to the constant k. On this point the writer examined the experimental results of many investigators, and found no approach to agreement as to the value of this alleged constant factor. It appears that the value to be assigned to k varies with the class of phenomena observed, and is affected by such considerations as whether the particle under transport is to be regarded as (*a*) an isolated body being transported over a bed of similar material, (*b*) an isolated body being transported over a bed of different material, either finer or coarser, or (*c*) an individual particle in a mass of similar material, the whole of which is in process of transport.

In endeavouring to obtain some idea of the speeds of the currents from which the Thanet Beds were deposited, search was first made for data which would afford a value for the factor k in the case of phenomena of type (*c*) above ; but, although a considerable amount of experimental work on the speeds of currents competent to transport sands and gravels of varying degrees of coarseness has

been done, the writer could discover no trustworthy case in which the work had been accompanied by accurate determination of the mean diameter of the material used in the experiments. Dr. John S. Owens,[1] however, made observations in the case of phenomena of type (*b*) above, and it was found possible to make use of his results. He carried out experiments on the transporting power of sea-currents, using flint pebbles ranging in diameter from half-an-inch to six inches. The pebbles were rolled by the currents over a sand surface. As a result of his experiments, Owens arrived at the formula :—

$$d = \frac{45V^2}{W - 64}$$

where d = diameter of pebble in inches
W = weight of a cubic foot of pebble material in pounds,
V = velocity, in feet/sec. of current just competent to transport the pebble.

Now it seems legitimate to argue that, where we have flint pebbles scattered throughout a bed of sand we may fairly assume that the same conditions were required for the deposition of the pebbles as for the sand. The observations of Owens, Vaughan Cornish, Gilbert, and others, have, however, shown that when arenaceous material is under transport by currents of lower velocity than 2·5 feet per second it invariably moves forward in the form of sand-ripples, and the rippled surface always arrests the movement of pebbles unless the velocity of the current is greatly in excess of that required to move them. According to the formula given by Owens, at a speed of 2·5 feet per second, a current would be able to transport flint pebbles up to 2·85 inches in diameter. Therefore, where we have a bed of sand with flint pebbles scattered fairly uniformly through it, and these pebbles clearly average less than 2·85 inches in diameter, we may assume that the current which transported the material to its present resting-place, and from which it was deposited, was *at least* as fast as that required to transport pebbles of the size seen, since the arrest and burial of these pebbles was probably brought about in consequence of the formation of sand-ripples on the bed. We may assume further, that the velocity of the current was not *greatly* in excess of that required to move pebbles of the size seen, for, had it been so, the sand-ripples would not have checked the pebbles in their career.

The Thanet Beds contain no flint pebbles, but after some search the writer selected a section in Blackheath Pebble Beds in which numerous flint pebbles, averaging less than 2·85 inches in diameter, but of notable uniformity of size, were evenly distributed throughout a bed of sand. A sample was taken containing both pebbles and sand. One hundred representative pebbles were selected and their

[1] Owens, "Experiments on the Transporting Power of Sea Currents": Geog. Journ., April, 1908, pp. 415–20.

total volume found by displacement. The diameter of the average pebble, assumed spherical, was then calculated. The result was 2·197 cm. The average specific gravity of the flint was then determined (2·59) and the weight in lb. of a cubic foot of flint calculated (161·69). These figures were then applied to Owens' formula thus :—

$$d = \frac{45V^2}{W - 64}$$

$$\cdot 02197 \times 39 \cdot 3708 = \frac{45V^2}{97 \cdot 69}$$

giving $V = 1 \cdot 37$ ft./sec.

This value may be taken as the *minimum* speed (probably not much below the true speed) of the current from which the sand associated with the pebbles was deposited. A minute mechanical analysis of the sand was next made, the elutriation-curve drawn, and the Equivalent Grade figure determined with great precision (·102 mm.). The sand proved, fortunately, to give a curve of remarkable similarity to a Thanet Sand of intermediate type, with a fairly high Grading Factor. The Equivalent Grade of the sand was taken as the representative diameter of the material. It was a figure on which much reliance could be placed, in view of the high Grading Factor. Then, by substitution in the formula

$$d = kV_c^2$$

the value to be assigned to the factor k (for transport of sand in bulk) was ascertained, thus :—

$$\cdot 102 = k \times (1 \cdot 37)^2$$

d being taken in mm. and V in feet per second.

Hence $k = \cdot 054$.

The value of k, as obtained directly from Owens' formula (by substituting in it the weight in lb. of a cubic foot of quartz), is of a much larger order than that obtained above, so that velocities calculated by means of it are much less than those obtained when taking the value indicated above. It has long been known, however, that an aggregate requires higher velocity to move it than does a single object. T. E. Blackwell demonstrated this in 1857, and Owens himself noted that the velocities required to move sand-grains in the mass were several times greater than the velocities as calculated from his formula, on substituting in it the diameter of the individual grains. In view of the use to which the above result was to be put, the writer thought it well to check the formula by repeating the experiment with a fresh sample of sand containing flint pebbles obtained from another area. A second sample was taken, this time from the lower part of the Woolwich and Reading Beds, at a spot many miles distant from the place whence the first sample had been obtained. The result was remarkable. The hundred representative pebbles gave an average diameter very near that obtained in the first experiment

(2·211 cm. as compared with 2·197 cm.), and the Equivalent Grade of the associated sand similarly gave a figure extraordinarily near that obtained in the case of the first sand (·106 mm. as compared with ·102 mm.). If this be not a singular coincidence it must indicate a significant connexion between the size of the pebbles in a sandy bed and the Equivalent Grade of the sand itself. With regard to the considerable variation often to be seen in the sizes of pebbles included in a sandy bed, it should be borne in mind that the *weight* of stone which a current can move varies as the *sixth* power of the velocity, and that therefore a slight increase in velocity may produce effects out of all proportion to what would be expected. The determination of k from the data of the second experiment gave ·056 as compared with ·054, the value obtained previously, and accordingly ·055, the mean of these two results, was taken. Hence, for the case of the transport, in bulk, of arenaceous material similar to that of which the Lower London Tertiary strata of the southern side of the London Basin are composed, the formula

$$d = \cdot 055\, V_c^{\,2}$$

where d is the Equivalent Grade of the material in mm. and V_c is the velocity in feet/sec. just competent to transport the material, is put forward with a certain amount of confidence.

Lower Thanet Beds.

	Beddington.	Charlton.	Swanley.	East Kent.
Equivalent Grade of material in mm.	·085	·059	·073	·037
Competent Velocity ft./sec.	1·24	1·03	1·15	0·82

Upper Thanet Beds.

	Charlton.	East Wickham.	Greenhithe.	Pegwell Bay.[1]
Equivalent Grade of material in mm.	·146	·120	·090	·042 for highest Thanet Beds seen.
Competent Velocity ft./sec.	1·63	1·48	1·28	0·87

[1] The highest Thanet Beds seen at Pegwell Bay really represent a fairly low level in the deposit, but these data are included here because they were used in the diagram (Fig. 8).

By means of the formula the speeds of the currents just competent to transport various types of Thanet Beds material were calculated. The velocities obtained may be regarded as minimum values for the rates of movement of the water from which the Thanet Beds were deposited.

The localities mentioned in the second table being approximately in alignment, from west to east, it is of interest to plot a graph showing the relation between competent velocities and distances. When this is done the points are found to lie on a curve of logarithmic type, and when competent velocities are plotted against the logarithms of the distances the points lie very nearly in a straight line (see Fig. 8). In the case of the Pegwell Bay data, however, the

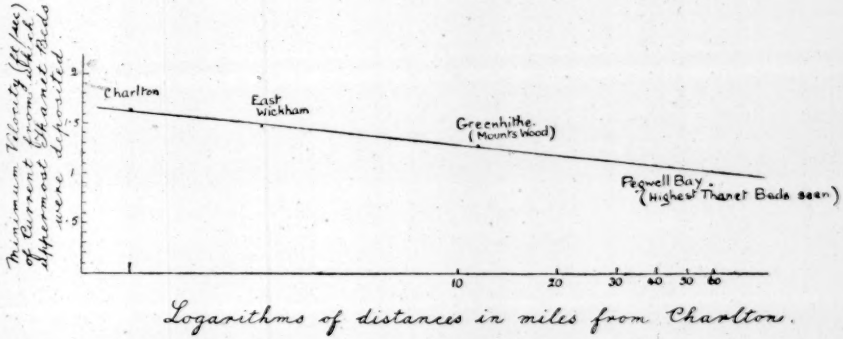

FIG. 8.

point lies somewhat below the line, but this is what was expected. The highest Thanet Beds seen at Pegwell Bay really belong to the lower part of the deposit, and higher values for the Equivalent Grade and competent velocity would have been yielded by a sample from a higher level, had one been available. These results suggest that we have here a hopeful line of research, the following up of which may be expected to yield comparative results of a reliable nature.

In view of the influence of shore-lines upon marine currents, the writer is of opinion that the construction of a map indicating the competent current values for the Thanet Beds of the London Basin could not fail to throw much useful light upon the question of the origin and development of the great trough.

The results of similar work upon the mechanical constitution of the Woolwich and Reading and Oldhaven Beds are reserved for future discussion.

REVIEWS.

SPECIAL REPORTS ON THE MINERAL RESOURCES OF GREAT BRITAIN. Vol. XI: THE IRON ORES OF SCOTLAND. By M. MACGREGOR, G. W. LEE, G. V. WILSON, T. ROBERTSON, and J. S. FLETT. Mem. Geol. Survey. pp. vii + 240, with 18 text-figures. Edinburgh, 1920. Price 10s. net.

THE fourth volume of this valuable series to be devoted to iron-ores gives a very complete and comprehensive account of those of Scotland, both of actual and potential value. The first section, of a historical nature, gives an interesting sketch of the early and very remarkable attempts at the smelting of iron-ores from England and elsewhere by means of charcoal derived from the forests of the Highlands, which seem to have had a real existence in those days, outside of the imaginations of English Socialist propagandists. Thus in the eighteenth century furnaces were erected for the smelting of iron in such extraordinary places as Bonawe, Glenkinglas, Invergarry, Strathspey, and Loch Maree, the ore being brought from the coalfields of Central Scotland and from Cumberland. Naturally this industry did not enjoy a long life, but strangely enough the Lorne Furnace at Bonawe seems to have struggled on spasmodically till 1876.

Effective iron-mining in Scotland may be said to have begun in 1760, when the Carron Ironworks started to smelt clayband ores with coal. Soon after this great development began in the Carboniferous bedded ores, giving rise to an industry of first-rate importance. The greater part of this memoir is naturally taken up by a detailed description of the occurrences of this type, which are found over a large area in the central parts of Scotland, ranging with intervals from Ayrshire to Fife, the greatest developments being in Lanarkshire and the adjoining counties, here called the Central Coalfield. This section cannot fail to be of the greatest value to Scottish mine-owners and geologists. Careful and apparently conservative estimates are made of probable and possible reserves.

The non-Scottish geologist will, however, undoubtedly turn with greater interest to the accounts here given of some of the side-shows, such as the Jurassic ores of Raasay and the remarkable veins of the Orkneys and Shetlands. The Raasay bed, which is now known to belong to the Upper Lias, though at first considered to be the equivalent of the Cleveland Main Seam, has actually been a producer, but it is doubtful whether it could be made to pay under peace conditions, owing to high cost of transport. An analysis of an average specimen of the raw stone, quoted in this memoir, gives 25·2 per cent of metallic iron with 2·3 per cent of phosphoric acid, while Dr. Hatch states that it averages about 23 per cent, with 0·9 per cent phosphorus. The stone is therefore of low grade.

We are glad to note that in this memoir a glossary is given of the extraordinary language in which the Scottish mining geologists

have effectively concealed their thoughts from the Southerner in other publications dealing with the coalfields of the same areas.

R. H. R.

INVERTEBRATE PALÆONTOLOGY: AN INTRODUCTION TO THE STUDY OF FOSSILS. By H. L. HAWKINS, M.Sc., F.G.S. pp. xix, 226, with 16 plates. London: Methuen & Co. 1920. Price 6*s.* 6*d.* net.

THIS book is apparently intended for those who are beginning the study of fossils, and also for students who have already some knowledge of palæontology. The first four chapters deal with the scope and aim of palæontology; the nature, occurrence, preservation, collecting, and preparation of fossils; and with stratigraphical and physiographical palæontology. These chapters are written in a clear and interesting style, and with the accompanying illustrations should prove attractive to beginners.

The second part of the book "is designed to give an epitome of the sequence of evolution as it has been unfolded in geological time". This part is divided into (1) Pre-Cambrian Faunas, (2) Lower Palæozoic Faunas, (3) Upper Palæozoic Faunas, (4) Mesozoic Faunas, (5) Cainozoic Faunas. By taking these relatively long time-divisions the author is able to give a more continuous account of the general evolutionary changes in the various groups of fossils than is possible when the life of each geological system is considered separately. But, as the author points out, this part of the book will be intelligible only to those readers who have some considerable knowledge of morphological and systematic palæontology; and the same remark applies to the preceding chapter on "Biological Palæontology", in which "an attempt has been made to give a general account of the broad outlines of phylogenetic evolution". The author here deals with the more modern lines of research in the Palæontology of the Invertebrata, in a way which should arouse the interest of students. We think it would have been an advantage if this chapter had been expanded and fully illustrated, since this aspect of Palæontology has been less frequently dealt with in textbooks than the subjects of the other chapters.

REPORTS AND PROCEEDINGS.

British Association, Cardiff, 1920.

SECTION C.—GEOLOGY.

1. Presidential address by Dr. F. A. BATHER, F.R.S. (see p. 473).

2. Professor A. HUBERT COX: Address on the Geology of the Cardiff District.

3. Dr. J. W. EVANS, F.R.S.: The Origin of the Alkali Igneous Rocks.

These rocks, distinguished by unusually high proportion of alkalies, relatively to alumina and lime, occur mainly where the crust of the earth

is thick, the heat-gradient low, and there has been no folding since remote times. Magmas appear to have reached surface by fault fissures from great depths where high pressures are associated with comparatively low temperatures. Crystallization proceeding under such circumstances, there would be an early formation of minerals with small molecular volumes, garnet, kyanite, epidote, and zoisite, minerals rich in lime and alumina. Zoisite may be regarded as high pressure representative of anorthite, but there is no corresponding representative of albite or orthoclase. Consequently we should expect a residual magma exceptionally rich in alkalies which would furnish material necessary for formation of alkali rocks.

4. Reports of Research Committees.

5. Joint meeting with Sections D and K. Discussion: Mendelism and Palæontology: The Factorial Interpretation of Gradual Changes, especially when New Characters appear late in the Individual Life-cycle. Dr. F. A. Bather, F.R.S.

The question posed. Can characters be regarded as independent, i.e. as manifestations of independent factors in the germ? Does evolution take place solely by addition or loss of such factors? Is there not also a gradual modification of the body, resulting in a continuous transition? Palæontologists find such transition to be the rule in those cases where the geological record is sufficiently complete. (See President's Address, Section C, heading "Continuity in Development".) Palæontologists support the theory of recapitulation, and believe that in many cases gradual modification of the adult and senile body is, in the course of race-history, pushed back to earlier growth stages. (See President's Address, Section C, heading "Recapitulation".) Can such cases be explained by independent factors in the germ? Does not that hypothesis involve, first, an alteration of the germ through change in the body, secondly the determination of that germinal change in a direction harmonious with bodily change?

Dr. R. Ruggles Gates:—

According to mutationist hypothesis, germinal characters arise as alterations of single elements of the germ plasm. This conception avoids the difficulties involved in considering the change as due to the loss or addition of a factor. It recognizes on the one hand the solidarity of the germ plasm as a whole, and on the other the independent origin of variations in its several parts. Such variations are termed karyogenetic, since they apparently arise in the nuclei and are perpetuated by miotic division. Mutations of this nature are almost universal amongst wild plants and animals, and some of them are so small that for general purposes they are practically continuous. They differ from the Darwinian conception of continuous variation, however, in that (i) they do not arise in any regular order, (ii) they are inherited as separate units. But recapitulation is an almost equally widespread phenomenon in animals, and to a less extent in plants. The recapitulation in animal embryos, and in such fossil groups as the Ammonites, implies the addition of terminal stages to the development of the organism. From the standpoint of organic structure this process is clearly different from a mutation by which the nuclear unit is modified throughout the organism. Recapitulatory characters thus fall into two groups: (i) embryonic, which appear always to imply adaptation of the organism to different conditions, and are best explained by the neo-Lamarckian principle; (ii) orthogenetic, which appear late in the life-cycle but are germinal in origin and non-adaptional.

Professor J. E. Duerden: Mendelism; Palæontology; Evolution.

Recent investigations in genetics in general give support to the factorial hypothesis, namely, that the characteristics of the body are represented in the germ plasm, in all probability in association with the chromosomes. Supporting evidence is forthcoming from sex, crossing-over and localisation. Any hereditary change in an organism must therefore be associated with factorial change in the germ plasm. Casual mutations readily admit of Mendelian interpretation, but evolution in general does not take place by changes of this kind. Evolution of species often seems to call for a similar change in the whole assemblage of individuals within an area, while palæontology and the study of numbers of related forms call for gradual successional changes in the same direction as regards any particular structure (orthogenesis). Mendelian experiments do not yet afford any great support for either of these demands. Observed mutational changes do not call for environmental influence, and are wholly apart from any adaptive considerations; natural selection plays no part in the origin or preservation of variations, but may be eliminative. It is highly questionable whether somatic or environmental influences can modify the germinal factors in definite directions, but disruptive changes and gradual loss of factorial vigour, or perhaps senility, may be contemplated, continued over long ages. As the common germ plasm of a race may at any one time be presumed to be in somewhat the same condition, evolutionary changes on somewhat similar lines may be expected.

Professor A. Dendy, F.R.S.

6. Dr. T. Franklin Sibly: The Old Red Sandstone of the Mitcheldean District, Gloucestershire.

Mitcheldean lies on the Gloucestershire–Herefordshire border 10 miles west of Gloucester, and in the latitude of the Breconshire Beacons. In this neighbourhood persistent westerly dips determine an outcrop of the whole of the Old Red Sandstone, with a thickness of some 7,500 feet, in a band scarcely 2 miles wide, bounded on the east by the Silurian strata of the May Hill anticline and on the west by the Carboniferous of the Forest of Dean coal-basin. The sequence of strata determined in this locality offers a possible key to the wilderness of Old Red Sandstone in Herefordshire.

7. Professor W. M. Flinders Petrie, F.R.S.: The Continuance of Life on the Earth.

If by any process of aggregation the earth has been at a red heat, all the lime and soda would be combined with the silica (now sandstone) and all the carbonic and hydrochloric acids would be in the atmosphere (now locked up in limestone and salt). The changes from that condition would consist in the acids gradually decomposing the silicates; at present there is only a minute fraction of the original carbonic acid left in the atmosphere. The decomposition of a few more inches of silicates over the globe will exhaust the carbonic acid, and life could not exist. This may take place in a few hundred thousand years, and such is the limit to vegetable and therefore to animal life, irrespective of solar cooling. The amount of carbon in the strata is probably enough to combine with all the oxygen of the air; hence, land-breathing animals were impossible until after the carbon had become separated and left oxygen free. This agrees with the appearance of air breathers after the Carboniferous age.

8. Dr. A. E. Trueman: The Liassic Rocks of Somersetshire and their Correlation.

The Liassic rocks of Somerset are thin but richly fossiliferous, yielding many large Ammonites. When followed towards the Mendips there is considerable reduction in thickness and marked lithological change. At several localities a white limestone resembling the Sutton Stone of Glamorgan is seen to rest on the Carboniferous Limestone; it is developed

at various horizons, and usually contains no Ammonites, but correlation can be made by means of species of *Ostrea* and *Gryphea*. In the numerous exposures near Radstock many non-sequences can be located, and maps showing the movement of intra-Liassic folds have been prepared.

9. Dr. J. K. CHARLESWORTH: The Glaciation of the North-West of Ireland.

The major part of the region investigated, including the Donegal Highlands and the Sperrin Mountains, was never invaded by the Scottish ice as currently supposed, but the Donegal mountains, in particular the Barnesmore Hills, formed a most powerful centre of radiation, whence ice streamed westwards to the Atlantic and eastwards over the Sperrin Mountains to Cookstown and beyond. In a south-easterly direction the ice passed obliquely across the Clogher Valley in Slieve Beagh to the Central Plain of Ireland, where was located the "central axis" of Hull and Kilroe. This axis of dispersal existed at no period of the glaciation.

10. Mr. L. DUDLEY STAMP: On Cycles of Sedimentation in the Eocene Strata of the Anglo-French–Belgian Basin.

The Eocene deposits of the great Anglo-Franco–Belgian Basin can be grouped naturally into a series of cycles of sedimentation—the Montian, Landenian, Ypresian, Lutetian, Ledian, and Bartonian. Each cycle commences with a marine invasion and passes from marine to estuarine and continental conditions. In England the changes are closely connected with the gentle, intermittent uprise of the Weald.

11. Dr. J. W. EVANS, F.R.S.: The Geological Structure of North Devon.

In early Permian times the Devonian and Carboniferous were thrown by pressure from the south into overfolds, with overthrust faults. A subsequent relaxation of pressure resulted in a slip back on the same fault-planes. There were also oblique tear-faults striking between north and west. A mountain region then sloped southward from the Welsh Coast to Mid-Devon and much material was transported in that direction. In the Triassic period, however, the Palæozoic had, as a whole, its present contours, including the great Glastonbury and Bristol Channel depression descending to the west, and its subsidiary valleys still partly filled with Mesozoic deposits. In Tertiary times there was renewed pressure from the south. This met with less resistance in the west, and there was consequently a relatively forward and downward movement on that side along the old tear-faults and possibly new fractures with the same general direction. In Pliocene times the land was more submerged than now, and the subsequent emergence seems to have continued in most places till a comparatively recent date.

12. Professor W. L. BRAGG: Crystal Structure.

The investigation into crystal structure, which has been made feasible by the discovery of the diffraction of X-rays by crystals, has led to a determination of the precise positions of the atoms in a number of the simpler crystalline forms. Recent theories of atomic structure such as those put forward by Bom and Lande, Debye, Lewis, and Langmuir, are largely based on the arrangement of the atoms in crystalline solids, since this arrangement affords an insight into the nature of the forces acting between the atoms. In such compounds as sodium chloride, it is probable that the atoms exist as ions of sodium and chlorine, and that the crystal is held together by the electrostatic attractions of these ions, thus accounting for the fact that there is no grouping of the atoms into molecules in the solid. In other compounds, such as those of two electronegative elements, the molecular arrangement persists in the solid state and the chemical combination appears to be of a different type

from that of sodium chloride. A consideration of the distances between the atomic centres in crystals supports the conception of the two types of chemical combination.

13. Mr. David Davies: Palæontology of the Westphalian and lower part of the Staffordian Series of the Coal-measures as found at Clydach Vale and Gilfach Goch, East Glamorgan.

Recorded: 45,000 plants; 1,000 shells; two insects and one fish scale. Plants yielded 154 species, shells six species, insects two species, fish scale one; forty-five of these are new to South Wales and seven new to Britain. Ecology of ten horizons: Equisetales predominate in four, Filicales and Pteridosperms in three, Lycopods in two, and Cordaitales in one horizon. When Lycopods predominate, Fern and Fern-like plants are weak, and vice versa. 37 per cent plants are common to both series; 31 per cent distinctly Staffordian; 32 per cent distinctly Westphalian. The Pennant Sandstone produced smooth round coal pebbles, giving evidence of a geological break. A significant feature is the appearance of new species at this period.

14. Mr. D. C. Evans: The Ordovician of Carmarthen.

This paper dealt with the stratigraphical succession and tectonic structures of the Ordovician rocks of Carmarthenshire.

Presidential Address to Section C (Geology).

Owing to unusual pressure on our space we are unable this year to reprint the President's address in full. For the following abstract and appreciation we are indebted to Dr. F. H. A. Marshall, F.R.S.

Dr. Bather's presidential address deals with the fundamental principles of Palæontology. He begins by pointing out that it is the time-concept which characterizes the subject and raises it above the mere description of extinct assemblages of animals and plants, and he proceeds to consider the effect of this concept on the principles of classification and on the ideas of relationship. In the light of palæontological study definitions of groups of animals or plants can no longer be purely descriptive; they must take account of ancestry and succession in time. As Dr. Bather expresses it: "The old form of diagnosis was *per genus et differentiam*. The new form in *per proavum et modificationem*." It has not been unusual to fall into the error that the apparent succession through a series of strata of similar forms of life implies descent, and Huxley, in his scheme of equine evolution, regarded *Palæotherium* as being in the line of direct ancestry of the modern horse. However, this species and the later *Anchitherium*, have been shown by Professor Osborn and his co-writers to belong to side-lines of descent. Occasionally an apparent succession is due to immigration of a distant relative from another region in the manner supposed by Cuvier in seeking to account for the renewal of life when an earlier fauna had disappeared. Dr. Bather goes on to consider the evidence of descent afforded by palæontological instances of the law of recapitulation, which is so well illustrated by the ammonites. In the next section of the address he points out that the "line upon line" method is the only absolutely safe way of advance in Palæontology, for mutation must be affiliated with mutation and species with species; the investigator must work his way back, "literally inch by inch through a single small group of strata," if he wants to be sure of his conclusions about lines of evolution. Concerning the question as to whether descent had taken place by continuous or discontinuous variation it is shown that contrary to what might have been expected, palæontological opinion is emphatically in favour of the former

view. With the species of the sea-urchin *Micraster* the changes undergone in the course of ages were apparently gradual in all the different characters, and many other instances of continuous evolution might be given. After brief references to the concepts of seriation or the direction of change, Dr. Bather proceeds to discuss the question of pre-determination, which many palæontologists seem to have accepted. The principle is thus expressed: "A race once started on a certain course will persist in that course; no matter how conditions may change, no matter how hurtful to the individual its own changes may be, progressive or retrogressive, up hill and down hill, straight as a Roman road, it will go on to that appointed end." The principle is allied to Driesch's concept of entelechy in ontogenetic development, and the question of its validity seems to be part of the wider problem as to whether teleological categories have any place in biological thought, a question which is answered in the negative by all men of science, excepting the small minority who adopt the attitude of Dr. J. S. Haldane. Dr. Bather next discusses adaptive evolutional "convergence" and passes on to consider Dollo's so-called law of irreversible evolution. He does well to insist that this law is a statement of observed fact, and, understood rightly, need not imply any inherent principle affirming the impossibility of reversal. The next sections deal with the "study of habitat" and "the tempo of evolution", which, it is shown, is variable, depending on changes in the outer conditions. This is illustrated by the comparative study of the development of whales, sirenians, and horses during the Tertiary period, the rate of evolution of these three groups varying with that of changes in the nature of the food. Thus the sirenians underwent a slow change because they retained the habit of feeding on soft water-plants, the horses developed more rapidly in correlation with their taking to the plains and becoming eaters of grain, while the whales, though at first their development was slow, from the Oligocene onwards changed with extraordinary celerity as they adopted and diversified new habits of feeding and living. In referring to the "rhythm of life", Dr. Bather concludes that the phenomenon must reflect the great rhythmic waves that have uplifted the mountains and lowered the deeps, as well as the smaller waves and ripples that have from time to time diversified the face of the earth. The address is throughout both suggestive and stimulating. It concludes on a note of sanguine anticipation for the future.

F. H. A. M.

CORRESPONDENCE.

FLINT PROBLEMS.

Sir,—All efforts to solve the problems of flint formation are likely to be unsuccessful unless we marshal all known facts and deal with them seriatim. At present I doubt if it is possible to give even a satisfactory definition of flint!

Many years ago I found flint at Margate and Studland Bay, which is clearly silicified chalk. In places silicification has not been completed, and these softer parts have been removed, leaving cavities. Near Corfe I came across nodules in the chalk which, with the exception of a thin external crust of flint, are entirely composed of soft, white cryptocrystalline silica. There are flint pebbles at Boscombe and Southbourne-on-Sea that are composed partly of the same cryptocrystalline silica[1] and partly of chalcedonic

[1] *Nature*, May 1, 1890.

and opaline silica. On Chesil Beach there are pebbles which appear to be nothing more or less than indurated colloid silica.

Again, we have at Rottingdean, Walmer, and other places, examples of flint filling up cracks and fissures in chalk that was evidently ex-marine at the time. In some places fractured flints have been repaired by such secondary precipitations of silica, in others (Freshwater) there has been no such reparation in the crushed flints, but at Alum Bay silicate of iron has acted as a cementing medium. At Corfe, though the conditions appear to be the same, I have found the cracks of crushed flints filled with calcite.

Near Faversham there are compound flint nodules, flints within flints—as many as four or five, formed one around the other, with evidence of a periodic cessation of the process of aggregation between each.[1] It is difficult to understand how such processes could operate either in ex-marine chalk or submarine ooze. Again, why are so many flint nodules hollow when they contain fossils? Did the gases of decomposition cause expansion before the silica became completely "set"? Why are cavities so often lined with crystalline quartz when fossils, or parts, are present, and with chalcedony when they are absent? I have frequently noticed this.

Our ignorance of the chemical and physical conditions prevailing at the bottom of the old chalk sea renders the work of the flintist very difficult. What do we know in reference to the pressure, temperature, and composition of the water at that time? Supposing flint existed originally in a colloid state on the sea-bed, then the sponges and other organisms, so often associated with flint, must have existed there too. But this postulates a hard bottom upon which such things would rest, not a soft one into which they would all sink and become buried in ooze. A friend of mine has a flint nodule from the chalk which has been formed around a piece of teredo-bored wood, and another example of a nodule with a nucleus of silicified wood may be seen in the Museum at Dover. Now, did these pieces of wood sink some 2,000 fathoms to the chalk ooze, and then become surrounded with colloid silica, which subsequently became flint? If not, did they, then, sink some depth into the ooze and become enveloped by it? If the latter, was the ooze surrounding the wood replaced by colloid silica, molecule for molecule, or was the ooze mechanically displaced by the colloid during its accrescence on the wood? If we cannot admit either of the foregoing we are driven to the conclusion that the silica was formed around the wood while suspended in the water. If objects suspended in water sink more slowly as the pressure increases, there might be time for the deposition of colloid silica around organisms before they reached their final resting-place in or on the ooze.

C. Carus-Wilson.

Strawberry Hill.
September 1st, 1920.

[1] *Nature*, June 28, 1917.

OBITUARY.

Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S.

BORN 1860. DIED JUNE 21, 1920.

DR. WHEELTON HIND was born at Roxeth, near Harrow, in 1860, and died after a comparatively short illness at Ashley, near Stoke-on-Trent, on June 21 of this year. He received his medical training at Guy's Hospital and London University, where he graduated M.D., and also gained the Fellowship of the Royal College of Surgeons. In 1884 he began practice in Stoke-on-Trent, and during the following thirty years established a reputation as one of the foremost surgeons in the district, being at the time of his death the senior member of the surgical staff of the North Staffordshire Infirmary.

So far as research work is concerned, Hind's interest in geology practically dates from his arrival in Stoke, for very shortly thereafter he made the first of a long series of contributions on local geology to the Transactions of the North Staffordshire Naturalists' Field Club. Amongst his earliest papers was one on the geology of Suffolk, which was incorporated in his father's book on the flora of that county. As might be expected from his location in a coal-mining district, most of his work related to the stratigraphy and palæontology of the Carboniferous rocks, especially of the lower members of that series. In an endeavour to find some key to the succession of these strata he soon extended his investigations to the corresponding rocks of Derbyshire, Lancashire, and Yorkshire, where he collaborated with Mr. J. A. Howe in a detailed examination of the Lower Carboniferous sequence of the Pendle Hill area. As a result of this work the hitherto recognized classification of this series underwent considerable modification by the recognition of the "Pendleside Series" of shales and thin limestones, with a characteristic fauna, as a group intermediate between the Carboniferous Limestone and the Millstone Grit and differing essentially, both in lithology and fossils, from the Yoredale Series. The development of this series in Derbyshire and Staffordshire was recognized, and it was also traced to the Isle of Man and Ireland.

The basis of Hind's stratigraphical work was the attempt to discover a series of life-zones by means of which the Carboniferous rocks could be subdivided and those in different districts correlated. For several years he acted as secretary of the British Association Committee on "Life-zones in the British Carboniferous Rocks", and not only collected assiduously himself but also identified much of the material obtained by others. The comparative lack of success in this work, so far as the Carboniferous Limestone is concerned, was possibly due to the fact that most of the collecting was done in the North Midland area, where continuous sequences are conspicuously absent. Even the results of Vaughan's brilliant researches

in the Bristol district have not been found easy of application to the northern series, although much of Hind's subsequent work was directed towards that end.

By the discovery of Pendleside zone-fossils in the Culm measures of Devonshire, Hind was able to show that the lower portion of the latter was homotaxially equivalent to the former, while the goniatite fauna of the higher Culm strata confirms Arber's conclusion that they are of Middle Coal-measures age. Despite military duties entailed by the War—Hind went to France as Lieut.-Colonel in command of the North Midland Territorial R.G.A., and later occupied responsible hospital posts in various districts—he found time to elaborate the series of goniatite zones, ranging from the *Posidonomya Becheri* zone of the Pendleside up to the Middle Coal-measures, which he had formulated in 1909, and, in conjunction with Dr. A. Wilmore, to apply them in a detailed re-examination of the Clitheroe district.

At an early stage in his work he recognized the necessity for a reinvestigation of the Carboniferous mollusca, and the fruits of this appeared in the form of three monographs on the lamellibranchs. In conjunction with Mr. J. T. Stobbs a chart was drawn up in which these fossils, especially the freshwater species, were utilized in the establishment of horizons in the North Staffordshire Coalfield. Hind also published an important paper on the molluscan fauna of the Scottish Millstone Grit, and recognized the relationship to the fauna of homotaxially higher beds in America and Russia. His most important palæontological work relating to rocks other than the Carboniferous was his description of the Silurian Lamellibranchs in Mrs. Gray's Girvan collection.

Elected a member of the Geological Society of London in 1891, he received the Lyell award in 1902 and the Lyell medal in 1917. He was also an honorary member of the Société Géologique de Belgique, as well as of several British Societies. When it is remembered that his geological work was done in such time as could be snatched from a busy professional life, one marvels that so much was achieved. In a period of thirty years, some four of which were spent on war service, his published papers numbered over eighty, while in addition his services in the identification of fossils were largely utilized by the Geological Survey as well as by private workers. Such an output was only rendered possible by his wonderful vigour and enthusiasm. Whatever the verdict of the future regarding the details of his work, Hind will be remembered as one of the pioneers in the elucidation of the relationships of the Carboniferous rocks.

A. S.

1889. "The Natural Features and Geology of Suffolk": in W. M. Hind, *Flora of Suffolk*.

"Notes on some interesting Geological Sections in North Staffordshire": Trans. N. Staffs. Field Club, vol. xxiii, p. 77.

"A Description of an Inlier of Carboniferous Limestone at Birchwood Moor": ibid., pp. 441–6.

1890. "Notes on the Curious Appearance produced by the Natural Bisection of some Spherical Concretions in a Yoredale Sandstone Quarry": Proc. Geol. Assoc., vol. xi, pp. 424–7.
With J. Ward and others. "Excursion to North Staffordshire": ibid., pp. 117–36.

1891. "The Geology of Whitmore": Trans. N. Staffs. Field Club, vol. xxv, p. 40.
"Notes on a Pre-Glacial River-bed at Stoke Road, Shelton": ibid., p. 53.

1893. "Description of a Slab from the Shale above the Kinder Scout Grit, Rabchester, Lancashire": Geol. Mag., Ser. III, Vol. X, p. 540.
"Additions to the Palæontology of North Staffordshire": Trans. N. Staffs. Field Club, vol. xxvii, p. 103.
"The Affinities of *Anthracoptera* and *Anthracomya*": Quart. Journ. Geol. Soc., vol. xlix, pp. 249–75.

1894. With Sir J. W. Dawson. "Note on the genus *Naiadites*, as occurring in the Coal Formation of Nova Scotia": ibid., vol. l, pp. 435–42.
Presidential Address: Trans. N. Staffs. Field Club, vol. xxviii, pp. 1–21.
"A Monograph on *Carbonicola*, *Anthracomya*, and *Naiadites*" (Part I): Palæont. Soc., vol. xviii, pp. 1–81, pls. i–xi.

1895. "A Monograph on *Carbonicola*, *Anthracomya*, and *Naiadites*" (Part II): ibid., vol xlix, pp. 81–170, pls. xii–xx.
"The Chalk Flints of North Staffordshire": *Colliery Guardian*, vol. lxx, p. 1038.

1896. With F. Barke. "The Boulder Drift in North Staffordshire": ibid., vol. lxxi, p. 461.
"On Zonal Divisions in the Carboniferous System": Geol. Mag., Dec. IV, Vol. III, pp. 255–61.
"A Monograph on *Carbonicola*, *Anthracomya*, and *Naiadites*" (Part III): Palæont. Soc., vol. l, pp. 171–82, pl. xxi.
"A Monograph of the British Carboniferous Lamellibranchiata" (Part I): ibid., pp. 1–80, pls. i–ii.

1897. "A Monograph of the British Carboniferous Lamellibranchiata" (Part II): ibid., vol. li, pp. 81–208, pls. iii–xv.
"Section in Carboniferous Limestone Shales at Tissington, on the New Buxton and Ashbourne Railway": Trans. N. Staffs. Field Club, vol. xxxi, pp. 115–17.
"On the Subdivision of the Carboniferous Series in Great Britain and the True Position of the Beds mapped as the Yoredale Series": Geol. Mag., Dec. IV, Vol. IV, pp. 159–69, 205–13.

1898. "The Life-zones of the Carboniferous Deposits of Europe": ibid., Dec. IV, Vol. V, pp. 61–9.
"A Monograph on the British Carboniferous Lamellibranchiata" (Part III): Palæont. Soc., vol. lii, pp. 209–76, pls. xvi–xxv.
"The Yoredale Series": *Colliery Guardian*, vol. lxxvi, pp. 709–10, 757–8.
"On Mr. W. Gunn's Correlation of the Carboniferous Rocks of England and Scotland": ibid., pp. 506–8.

1899. With others. "Life-zones in the British Carboniferous Rocks": ibid., vol. lxxviii, pp. 702–4. Report Brit. Assoc. for 1898, p. 529.
"The Subdivision of the Carboniferous Series in Great Britain and some of their European Equivalents": Trans. Edinburgh Geol. Soc., vol. vii, pp. 332–60.
"What are the Real Equivalents of the Yoredale Rocks of Wensleydale in the Midlands?": Trans. N. Staffs. Field Club, vol. xxxiii, p. 67.
"On the Correlation of British and European Carboniferous Beds": Trans. Manchester Geol. Soc., vol. xxvi, p. 96–112.
"On Three New Species of Lamellibranchiata from the Carboniferous Rocks of Great Britain": Quart. Journ. Geol. Soc., vol. lv, pp. 365–70.

With W. Gibson. "The Agglomerates and Tuffs of Congleton Edge": ibid., pp. 548–59.

"On the Occurrence in British Carboniferous Rocks of the Devonian genus *Palæoneilo*, with a description of New Species": Proc. Geol. Soc., pp. 18–19; Quart. Journ. Geol. Soc., vol. lvi, pp. 46–9. 1900.

"A Monograph of the British Carboniferous Lamellibranchiata" (Part IV): Palæont. Soc., vol. liii, pp. 277–360, pls. xxvi–xxxix.

With H. A. Bemrose. "Long Excursion to Derbyshire": Proc. Geol. Assoc., vol. xvi, pp. 221–5.

1900. "A Monograph of the British Carboniferous Lamellibranchiata" (Part V): ibid., vol. liv, pp. 361–476, pls. xl–liv.

"*Scaldia minuta*": Trans. N. Staffs. Field Club, vol. xxxiv, pp. 93–4.

"Report on Carboniferous Rocks and Fossils, South Pennine District": Report Brit. Assoc. for 1899, pp. 371–5.

1901. "Life-zones in the British Carboniferous Rocks": ibid., for 1900, pp. 340–2.

With J. A. Howe. "The Geological Succession and Palæontology of the Beds between the Millstone Grit and the Limestone Massif at Pendle Hill and their Equivalents in certain other parts of Britain": Quart. Journ. Geol. Soc., vol. lvii, pp. 347–404.

"A Monograph of the British Carboniferous Lamellibranchiata" (Vol. II, Part I): Palæont. Soc., vol. lv, pp. 1–34, pls. i–vi.

"The Carboniferous Limestone of Lilleshall": Trans. N. Staffs. Field Club, vol. xxxv, pp. 1–3

1902. "A List of Localities where Fossils occur in the Pendleside Series of the Country round North Staffordshire": ibid., vol. xxxvi, pp. 77–80.

"On the Characters of the Carboniferous Rocks of the Pennine System": Proc. Yorks Geol. Soc., vol. xiv, pp. 422–64.

"The Sequence of the Carboniferous Rocks in North Staffordshire": Trans. Inst. Min. Eng., vol. xxii, pp. 219–27.

The Geology of Staffordshire.

Review of *The Geology of the Country around Stoke-on-Trent* (Mem. Geol. Surv.): GEOL. MAG., Dec. IV, Vol. IX, pp. 563–7.

"The Life-zones of the British Carboniferous Rocks": Rep. Brit. Assoc. for 1901, pp. 288–96

1903. Ditto: ibid., for 1902, pp. 210–16.

"On a New Species of *Solenopsis* from the Pendleside Series of Hodder Place, Stonyhurst": Quart. Journ. Geol. Soc., vol. lix, pp. 334–6.

"Notes on some Lamellibranchiata obtained by Mr. A. J. C. Molyneux from the Sengwe Coalfield": ibid., p. 287.

"Notes on some *Dictyonema*-like Organisms from the Pendleside Series of Pendle Hill and Poolvash": Proc. Geol. Soc., p. 80.

And others. "Whitsuntide Excursion to North Staffordshire": Proc. Geol. Assoc., vol. xviii, pp. 173–84.

And J. T. Stobbs. "Chart of Fossil Shells found in connection with Seams of Coal and Ironstone in North Staffordshire": Newcastle-under-Lyme.

"A Monograph of the British Carboniferous Lamellibranchiata" (Vol. II, Part II): Palæont. Soc., vol. lvii, pp. 35–124, pls. vii–xxi.

1904. Ditto (Vol. II, Part III): ibid., vol. lviii, pp. 125–216, pls. xxii–xxv.

"On the Homotaxial Equivalents of the Lower Culm of North Devonshire": GEOL. MAG., Dec. V, Vol. I, pp. 392–403, 526, 584–7.

"Life-zones in British Carboniferous Rocks": Rep. Brit. Assoc. for 1903, pp. 185–92.

1905. Ditto: ibid., for 1904, pp. 226–37.

"On the Beds which succeed the Carboniferous Limestone in the West of Ireland": Proc. Roy. Irish Acad., vol. xxv*b*, pp. 93–116.